A Trace Element Study of Process Streams with Potential Discharge to Flare Stacks at Selected Sour Gas Plants in The Province of Alberta

Waterton-Shell Canada Resources Limited
Pincher Creek-Gulf Oil Canada Limited

for

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SUMMARY

A collection system was designed and constructed to facilitate safe and representative sample acquisition from process lines carrying high pressure gas streams (up to 1000 psig) containing high levels of hydrogen sulfide (up to 70% H_2S). This device was fundamental to the comprehensive sampling program carried out at the Shell Canada Resources Limited - Waterton and Gulf Oil Canada Limited-Pincher Creek Sour Gas Plants to establish the presence and levels of 29 metals in 6 process streams that could be diverted to flare stacks in the event of plant upset conditions.

The presence of aluminum, arsenic, cadmium, chromium, copper, iron, lead, manganese, nickel and zinc was established consistently in the 6 process streams of the Gulf-Pincher Creek Sour Gas Plant. Antimony, beryllium, boron, lithium, mercury, molybdenum, silver and vanadium were identified at least once during the 3-test sampling program.

At the Shell-Waterton facility only cadmium, chromium, iron, manganese and zinc were found regularly in each of the 6 process streams sampled. Aluminum, antimony, arsenic, beryllium, copper, lead, mercury, nickel, scandium, selenium and silver were detected at least once at one or more of the sampling locations.

In order to assess the impacts of atmospheric emissions from flare stacks on surrounding communities it is essential to evaluate the volumetric flow rates of each of the process streams

that can be flared in the event of a plant upset condition, the historical frequencies with which individual process streams have been directed to flare stacks and the average time intervals over which individual process streams have been diverted to flare stacks.

It is recommended that a comprehensive survey be carried out at the Shell-Waterton Sour Gas Plant to establish the magnitudes of metal inputs into the process streams as a result of additions of processing components, bactericides, corrosion inhibitors, scale inhibitors and antifoam agents.

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I BACKGROUND

This study was initiated in response to a request made by Mr. V. Millard, Chairman and Dr. H.F. Thimm, Senior Environmental and Technical Advisor, Environment Protection Department of the Energy Resources Conservation Board (ERCB) after the public meetings held at Pincher Creek and Calgary, Alberta on October 14-15, 1982. The objective and scope of this investigation were reviewed and defined in group consultations between Dr. H.F. Thimm and Dr. A.W. Gnyp and Dr. C.C. St. Pierre of the Department of Chemical Engineering, University of Windsor.

Site inspections of the Gulf-Pincher Creek and Shell-Waterton sour gas plants were carried on October 15, 1982 by Dr. H.F. Thimm, Mr. R.J. Farion, Senior Inspector, Gas Plant Inspection, ERCB, Dr. A.W. Gnyp and Dr. C.C. St. Pierre.

Mr. Frans Mully assisted in the idenficiation of potential sampling sites at the Gulf-Pincher Creek facility.

Mr. Neil Camarta, Technical Superintendent, briefed the group on the operation of the Shell-Waterton plant before conducting a tour of the complex.

At the end of each plant tour samples of sulfur from the stock piles were collected for determination of metal concentrations in the visibly different layers.

A. OBJECTIVE

The objective of this study was to establish the levels of 29 trace metals, (selected for the earlier incinerator stack emission testing program (1,2)), in process streams that could be diverted to flare stacks in the event of plant upsets at the Gulf-Pincher Creek and Shell-Waterton sour gas plants.

B. SCOPE

On the basis of the two site inspections and comprehensive analyses of pertinent flow sheets a number of sample collection sites were established for each plant.

1. In-Plant Sampling Locations

All sampling locations were established in consultation with Dr. H.F. Thimm of ERCB.

a. Pincher Creek Gas Plant (Gulf Oil Canada Limited)

Sampling procedures were designed to optimize representative sample collection of

- raw sour gas leaving the Inlet Separators (at the Amine Contactor Inlet)
- sweet gases leaving the Amine Contactors
- Condensate Stabilizer overhead material
- wet sweet gas entering the Dehydration Contactors
- sales gas ready for distribution through pipelines to existing markets
- acid gases leaving the Amine Contactors (at the inlet to the Sulfur Plant)

b. Waterton Gas Plant (Shell Canada Resources Limited)

Arrangements were made to optimize representative sample acquisition of

- raw sour gas leaving the Slug Catcher (at the inlet to the Lean Oil Absorption Units)
- Lean Oil Absorber overhead material flowing to the Sulfinol Sweetening Units
- sweet wet gas entering the Dessicant Dehydration Unit
- sales gas leaving the Dessicant Dehydration Unit
- Condensate Stabilizer overhead material
- tail gases from the Sulfur Plants (at the entrance to the SCOT Unit).

2. Trace Element Determination in Process Streams

Three complete trace element determination tests were carried out at each plant using sampling procedures and equipment mutually agreed to with Dr. H.F. Thimm of ERCB. Each test involved individual sample acquisition over a 4 hour period at six selected locations.

Samples corresponding to each location were to be recovered from four distinct parts of the sampling train to provide

- sampling line washes
- filter catches
- ice-bath impinger catches
- dry ice-acetone bath impinger catches.

When severe filter integrity problems restricted sampling capabilities, the filter medium was removed from the system.

Consequently laboratory analyses were done on two fractions consisting of

- sampling line and filter holder washes
- combined impinger assembly catches

for each selected sampling location.

On-site gas chromatographic analyses were performed for estimation of saturated hydrocarbon (methane through pentane) levels in order to establish the molecular weights of the sampled streams.

The moisture contents of the process streams were determined by the condensation method with corrections for saturated hydrocarbons (propane through pentane) collected in the impinger assemblies.

3. Trace Element Analyses

The two fractions corresponding to each sampling location were analyzed for the 29 trace elements listed in Table 1.1. These elements were selected for earlier investigations (1,2) after a comprehensive review of open literature and discussions with personnel from Canadian and American regulatory agencies as well as ERCB representatives.

For common metals (exclusive of hexavalent chromium, arsenic, selenium, mercury and vanadium) the samples were ultimately dissolved in dilute hydrochloric or nitric acid and the resulting solutions were analyzed by an atomic absorption spectrophotometer using a hollow cathode lamp for the specific

TABLE 1.1 Trace Metals of Interest

Element	(Symbol)	Element	(Symbol)
Silver	(Ag)	Manganese	(Mn)
Aluminum	(Al)	Molybdenum	(Mo)
Arsenic	(As)	Nickel	(Ni)
Boron	(B)	Lead	(Pb)
Beryllium	(Be)	Antimony	(Sb)
Cadmium	(Cd)	Scandium	(Sc)
Cobalt	(Co)	Selenium	(Se)
Chromium	(Cr)	Tin	(Sn)
Copper	(Cu)	Strontium	(Sr)
Iron	(Fe)	Tellurium	(Te)
Gallium	(Ga)	Titanium	(Ti)
Germanium	(Ge)	Thallium	(Tl)
Mercury	(Hg)	Vanadium	(V)
Indium	(In)	Zinc	(Zn)
Lithium	(Li)		

metal. Two recoveries and two laboratory blanks were analyzed with each series of samples.

Samples of arsenic, selenium and vanadium were analyzed using a furnace (electrothermal) technique which yields greater sensitivity and lower limits of detection (3) than direct flame atomization. Mercury was determined using the cold vapour method in which mercury vapour was generated with 20% stannous chloride for purging into the atomic absorption detection cell.

II SAMPLING METHODOLOGY

In order to minimize risks to sampling team personnel a representative of the plant safety group monitored the activities at each site during each sampling period.

A. INTRODUCTION

A literature search and discussions with Canadian and American regulatory agency personnel indicated that there are no established reference methods for the sampling and analysis of trace elements circulating in process streams of chemical processing plants.

The high process line pressures (over 100 psig) presented significant sampling challenges. The most critical problem was successful design and construction of a reliable sampling train that would operate safely at pressures approaching 50 psig with minimal sample contamination, but convenient sample recovery.

Sampling and analytical methodologies were developed to provide:

- collection of a representative sample
- minimal sample loss in the train and minimal contamination by sampling train components
- quantitative recovery of samples from all parts of the train

- sample pretreatment procedures that optimized solubilization and concentration but minimized interference problems
- capabilities of instrumental trace metal determinations in the presence of unknown amounts of other particulate matter.

The simplicity of the newly designed sampling train permitted sample acquisition by a single operator at each location.

B. DEVELOPMENT OF SAMPLING STRATEGY

Since there were no established reference methods for sample acquisition from process streams in chemical plants, sampling sites at the designated locations were determined by the availability of existing facilities or convenience of installing new ones. In addition it was necessary to design and construct a sample collection system that would operate safely and reliably when connected to process lines carrying high pressure gas streams (up to 1000 psig) containing high levels of hydrogen sulfide (H_2S) ($\approx 70\% H_2S$).

1. Location of Sampling Sites

The general sampling locations at each plant were established in consultation with Dr. H.F. Thimm of ERCB.

a. Pincher Creek Gas Plant (Gulf)

Figure 2.1 illustrates the relative arrangement of sampling sites, with respect to Process Units, that provided

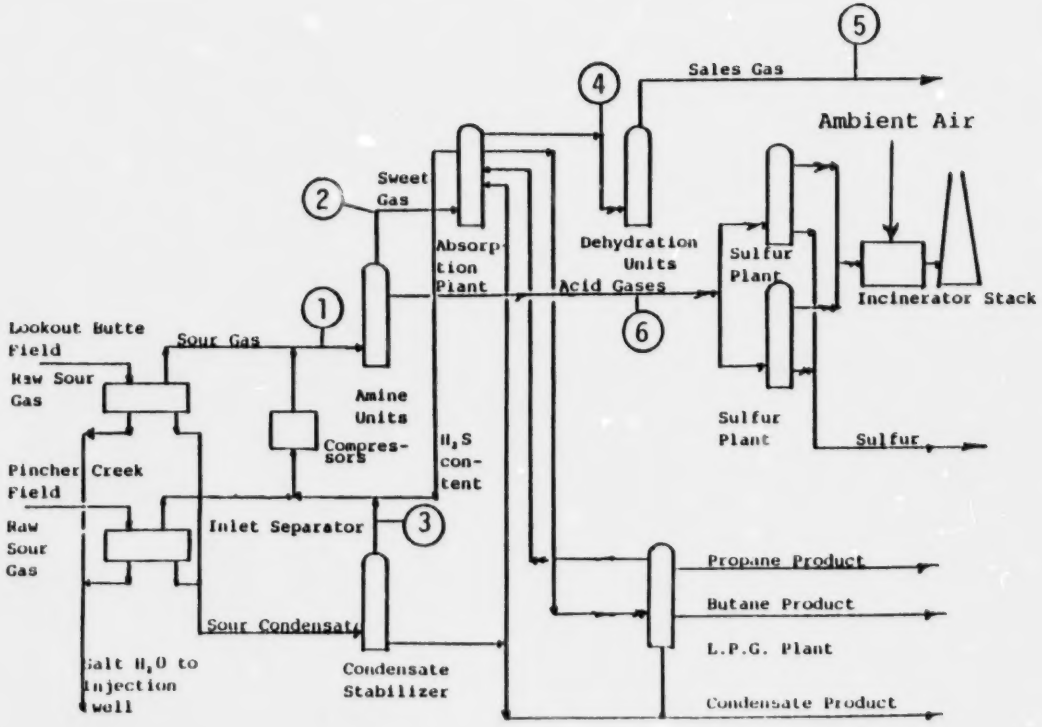


Figure 2.1 Simplified Flow Schematic for Gulf Oil Canada Limited Pincher Creek Gas Plant Showing Sampling Locations

sample acquisition of:

1 raw sour gas leaving Inlet Seperators for Amine Contactors

2 sweet gases leaving Amine Contactors

3 Condensate Stabilizer overhead material

4 wet sweet gas entering the Dehydration Contactors

5 sales gas

6 acid gases flowing from the Amine Contactors to the Sulfur Plant.

b. Waterton Gas Plant (Shell)

The relative arrangement of sampling sites, with respect to Process Units, that provided sample acquisition of

1 raw sour gas leaving the Slug Catcher for the Lean Oil Absorption Unit

2 Lean Oil Absorber overhead material flowing to the Sulfinol Sweetening Units

3 sweet wet gas entering the Dehydration Unit

4 sweet dry sales gas leaving the Dehydration Unit

5 Condensate Stabilizer overhead material

6 tail gases from Sulfur Plants flowing to the SCOT Unit.

is illustrated in Figure 2.2.

2. Design of Sample Collection System

Equipment needed for sample collection from high pressure process lines must be significantly different from the conventional source sampling trains specified in reference

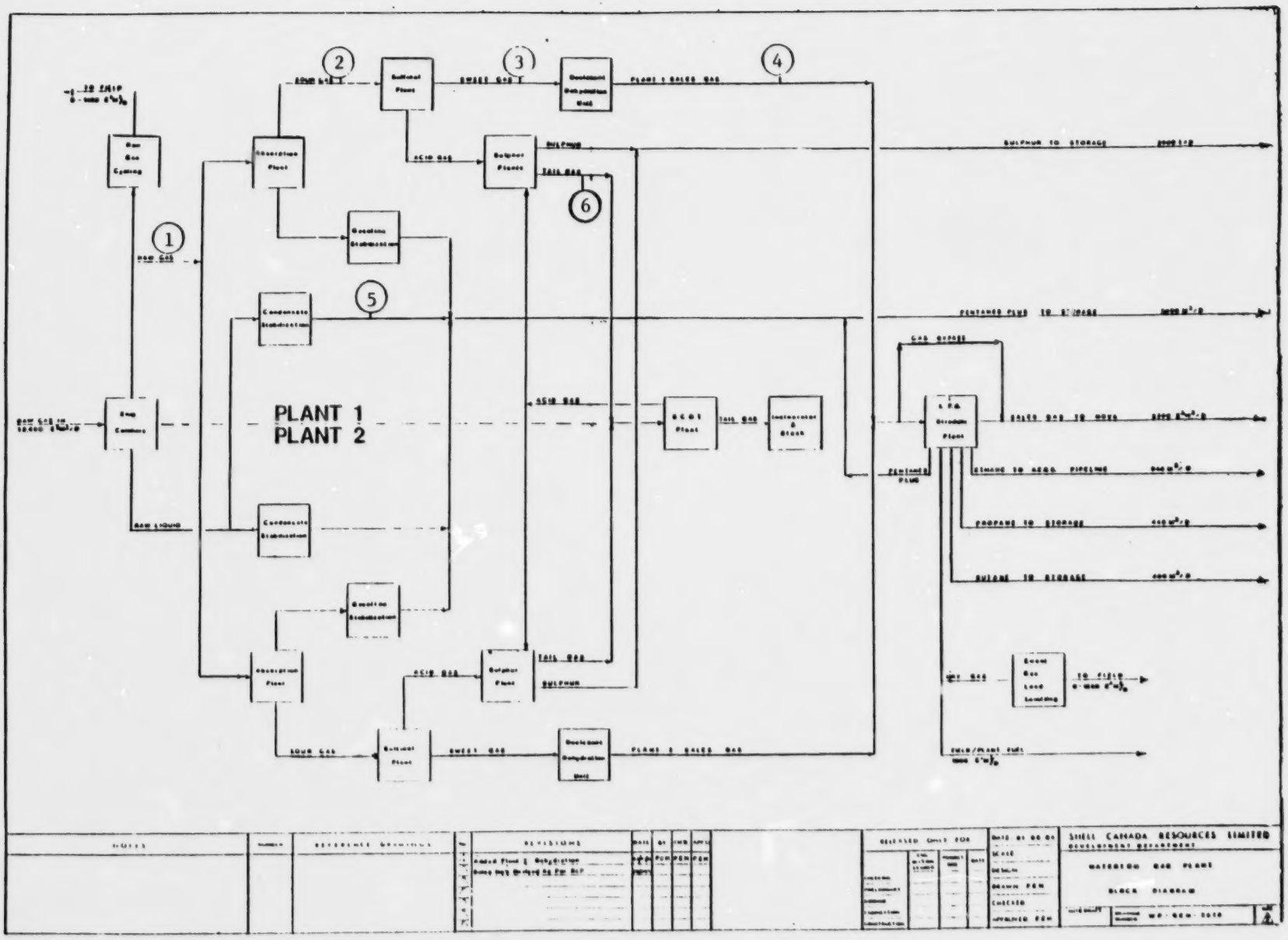


Figure 2.2 Waterton Gas Plant Block Diagram Showing Sampling Locations

methods such as the Alberta Environment Stack Sampling Code Reference Methods (AERM)(4). Since sample acquisition could be carried out only from standard fittings attached to pressure reducing valves, isokinetic sampling was impossible. Instead, emphasis was focussed on safe operation under conditions of high pressure (>100 psig) and high H_2S concentrations ($\approx$70%H_2S).

Figure 2.3 illustrates the basic sampling train that was designed and constructed for this investigation. In order to extract and transport the samples from the process lines to the collection media with minimal contamination, Teflon parts were used whenever possible. The choice of components and absorbing solutions represents an optimum in terms of a single procedure for sampling and pretreatment of all the elements of concern, although such pretreatment might not be best on an individual element basis.

a. Apparatus

All custom designed components of the sampling train illustrated in Figure 2.3 were fabricated in the University of Windsor, Department of Chemical Engineering Workshop by Mr. G. Ryan. Construction emphasized safety and compactness.

i. Sampling Line

The sampling line consisted of a 2-foot length of 3/8 inch ID Teflon tubing having a wall thickness of 1/16 inches.

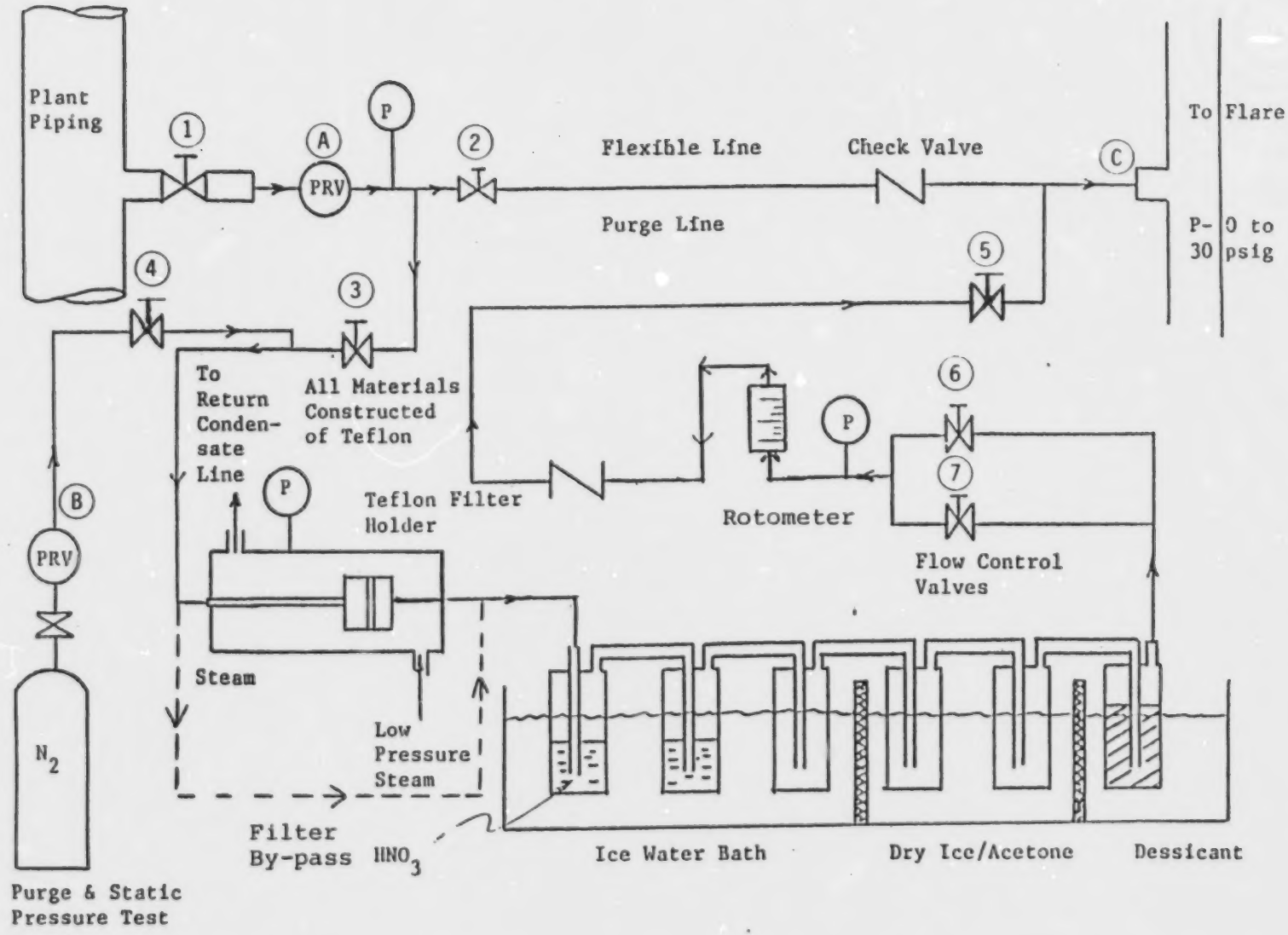


Figure 2.3: Sampling Strategy for Flare Stack Stream Investigations

ii. Filter

A holder for 3.7 cm diameter filters was fabricated from Teflon. The filters rested on a 3.7 cm Teflon support plate.

Several filter media have collection efficiencies greater than 99% (for 0.3 micron dioctyl phthalate particles) for face velocities of 12 to 125 cm/s. The conventional glass fibre filter material manufactured by Reeve Angel (Whatman, Inc.) Type 934 AH and the Ultra-Pure QM-A quartz micro fibre filters, supplied by Whatman, were selected for blank metal checks (See Appendix I for technical data). A special run of the 12.5 cm diameter QM-A quartz micro fibre filters was made by Whatman (5) who supplied 100 without cost for previous studies (1,2).

The QM-A quartz filters, which were found to have lower trace element concentrations in the series of blank analyses conducted in the laboratory (1,2) were used in this study. For 0.3 micron dioctyl phthalate smoke particles the QM-A quartz materials were found to have 99.95% collection efficiency (6).

Filter use was discontinued after severe difficulties were experienced during initial tests as a result of filter deterioration at the high sampling pressures.

iii. Sampling Line-Filter Heater

Condensation of moisture and hydrocarbons inside the sampling line and filter holder was eliminated by passing low pressure steam through the steam chest enclosing these sampling train components as shown in Figure 2.3.

iv. Impinger Train

Six impingers of the modified Greenburg-Smith type were constructed from Teflon bottles and tightly fitting caps that were secured with custom-designed clamps. Connections between impingers were made with Teflon tubing.

As illustrated in Figure 2.3 the first three impingers were immersed in an ice-water bath to condense water vapor and hydrocarbons as well as to enhance capture of submicron particulate material passing through the filter.

The fourth and fifth impingers were surrounded by a dry ice-acetone slush to provide traps for any materials that might escape collection in the preceeding components of the sampling train. Earlier studies of sour gas plant incinerator stack emissions showed that dry ice-acetone cooled impingers were needed to trap some metallic species (1,2).

Although a mixture of nitric and hydrochloric acids would be superior for dissolution of the trace metals, the presence of chloride during evaporation of the excess acid could result in significant losses of volatile halides (arsenic, selenium and vanadium). A six molar nitric acid concentration was chosen since this strength was successfully employed in an earlier study (3). Eight molar concentrations have also been employed by previous investigators (6).

Deionized, distilled water, provided by the Energy Resources Conservation Board laboratory in Edmonton, was prepared following the procedure outlined in Appendix II. Trace metal

grade Baker nitric acid from Lot No. 218042 was used to prepare the 6M solutions. Appendix II summarizes the composition of this reagent.

The last impinger contained Drierite (mesh size 10-20) which was discarded after each run. Loss of moisture removal capacity and erroneous moisture levels were readily detected by the blue to pink colour change.

Table 2.1 summarizes the basic arrangement of the trace element impinger train.

Table 2.1 Trace Element Impinger Train

Impinger Number	Contents (gm)	Immersion Bath Temperature (^{o}C)
1	100 6 M nitric acid	0
2	100 6 M nitric acid	0
3	Empty	0
4	Empty	-80
5	Empty	-80
6	250-dessicant	0

v. Control Module

Flow through the sampling train was regulated by means of the Coarse (6) and Fine (7) Control Valves shown in Figure 2.3. Since a dry test meter could not be used at high pressures, a rotometer placed in the line provided a means of measuring the sampling rate and evaluating the total sample volume collected.

vi. Leak Test

Although on-site sample collection was carried out after process line pressures were reduced to 25 psig, the sampling train was designed to operate without leaking even if pressures reached 50 psig. This margin of safety was needed to ensure safety of personnel collecting samples from lines carrying streams containing up to a maximum of 70% H_2S.

The complete sampling train assembly was leak tested before each sampling period after connections were made to the Process Line Reducing Valve (A) and Exhaust to the Flare (C). With Valves (3 and 5) fully closed the sampling train assembly was pressurized with nitrogen to 50 psig by opening the Pressure Reducing Valve (B) and Valve (4). Pressure integrity had to be maintained for 3 minutes before sampling was initiated.

vii. Sampling Conditions

A complete plant test involved individual sample acquisition over a 4 hour period at each of the six selected locations.

After the leak test was completed Valve (4) and Pressure Reducing Valve (B) were closed. With Valves (3 and 5) closed, the process line sampling connections were purged by opening Valves (1 and 2) and setting Pressure Reducing Valve (A) between 15 and 25 psig.

Sample collection was initiated by closing Valve (2) and opening Valves (3 and 5). Flow through the sampling train was regulated by adjusting the Coarse (6) and Fine (7) Flow Control Valves.

Table 2.2 summarizes the ranges of test conditions for this sampling program.

Table 2.2: Summary of Test Conditions

Number of Sampling Locations per Plant	6
Sampling Time per Location	3 to 4 hours
Total Sample Volume per Location	250 to 320 ft^3
Sampling Rates	1 to 1½ cfm

C. DETERMINATION OF GAS COMPOSITION AND MOLECULAR WEIGHT ON A DRY BASIS

The molecular weight of each process line gas stream was evaluated by collecting a gas sample using a pre-evacuated stainless steel bomb and analyzing the contents with the gas chromatograph at the Shell Canada Resources Limited Waterton Gas Plant.

The moisture content of each process line gas stream was obtained employing the condensation procedure of Method 3 (AERM)(4). This determination was made simultaneously with the trace element sampling program.

The mass of condensate collected in the impingers and dessicant (Drierite) was determined by weighing all containers before and after sampling to the nearest 0.1 gm.

This water mass was converted to an equivalent gaseous volume. The volume fraction of moisture in any gas stream was calculated using the corresponding total gas sample volume at reference conditions ($530^{o}R$, 29.92 inches Hg).

III PROCESS DESCRIPTIONS

In order to allow effective correlation of the trace element sampling program to plant operating conditions, Mr. H. Bratrud, a Gas Plant Inspector with the ERCB, was present in the control room for all tests and in constant touch with the source sampling teams. Before, during and for several hours after each test run the information summarized in Table 3.1 was recorded on an hourly basis.

Table 3.1 Process Information Obtained at Each Plant on an Hourly Basis for Each Test Run.

RAW GAS INLET FLOW RATE
PLANT SALES GAS FLOW RATE
FEEDRATE TO SULPHUR PLANT
FEED TO FLARE STACK
STACK TEMP. (TOP AND BOTTOM)
STACK FLOW RATE
SO_2 CONCENTRATION

Process flow sheets and technical literature describing the processes at each plant were obtained during an earlier study (2).

A. PINCHER CREEK GAS PLANT (GULF OIL CANADA LIMITED)

Figure 3.1 provides a detailed flow diagram for the Pincher Creek Gas Plant. A simplified version is illustrated in Figure 3.2. The raw sour gases from the Lookout Butte and Pincher Creek Fields have hydrogen sulfide (H_2S) contents ranging from 3.9 to 11 per cent. Entrained hydrocarbon liquids and water are removed from the entering wet sour gas stream in the Inlet Separator. The water is returned to the field for disposal through Injection Wells. The sour hydrocarbon condensate from the Inlet Separators is fed to the Condensate Stabilizer where hydrogen sulfide (H_2S) and lighter hydrocarbons are removed to leave a stable condensate product.

Deliquified sour gases from the Inlet Separators are combined with the sour gases recovered from the Condensate Stabilizer for treatment in the Amine Units. The acid gases removed from the Amine Units contain hydrogen sulfide (H_2S) and carbon dioxide (CO_2) which are fed to the Sulfur Plants for production of elemental sulfur. Emission of hydrogen sulfide to the atmosphere is minimized by incinerating the gases leaving the sulfur plants prior to venting through the tall stack.

Sweet gases leaving the Amine Units are fed to the Absorption Plant where residual heavier hydrocarbons and hydrogen sulfide (H_2S) are removed. The hydrogen sulfide (H_2S) is compressed along with that recovered from the Condensate Stabilizer and recycled to the Amine Units.

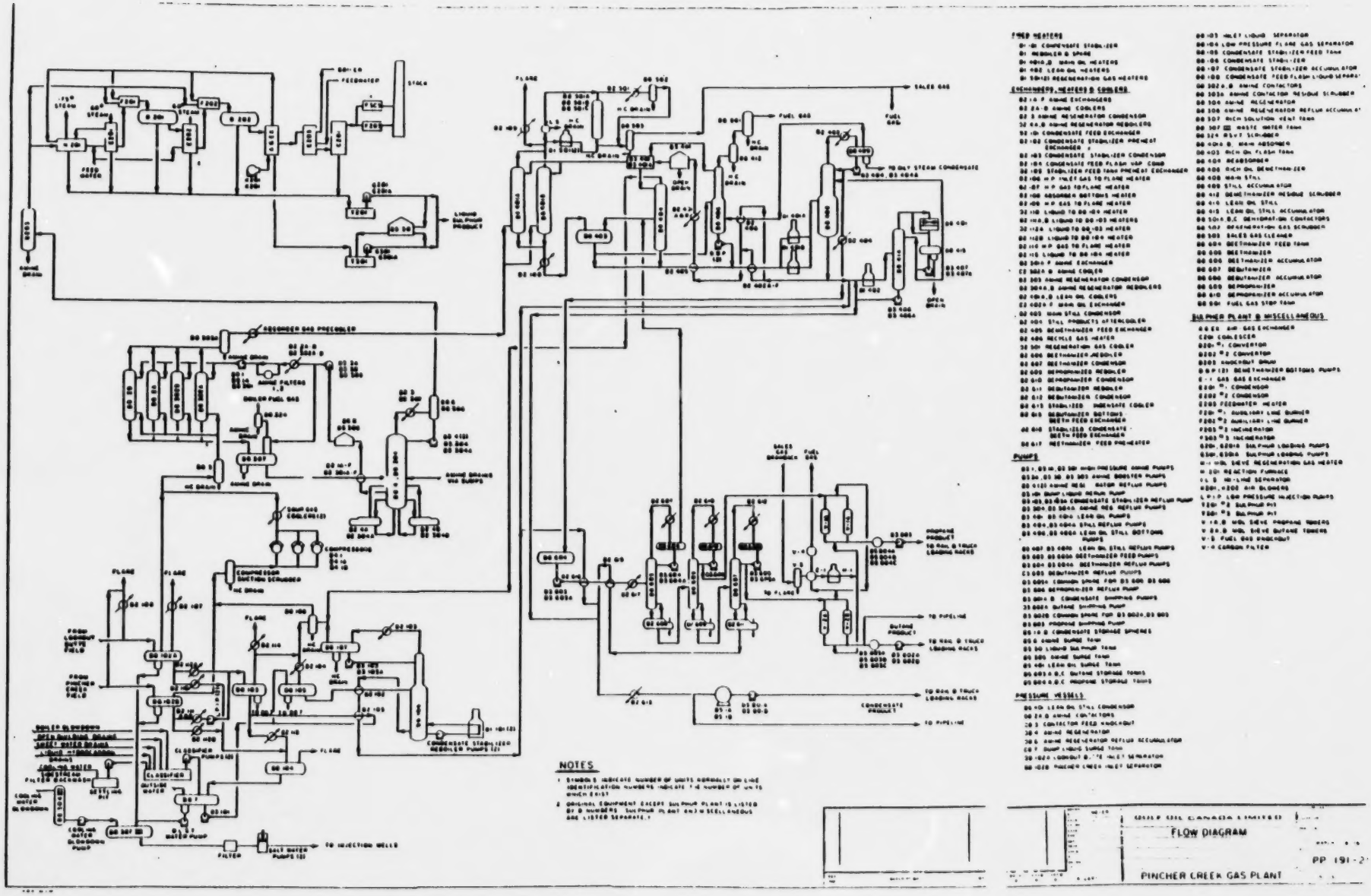


Figure 3.1: Detailed Flow Diagram for Pincher Creek Gas Plant

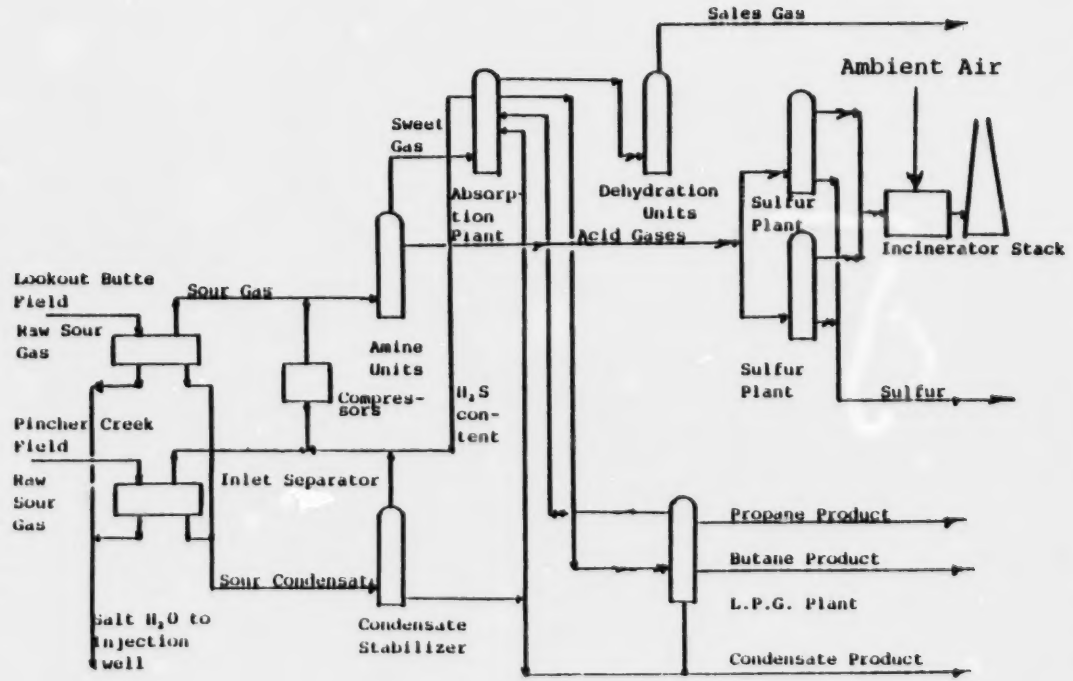


Figure 3.2 Simplified Flow Schematic for Gulf Oil Canada Limited Pincher Creek Gas Plant

Gases leaving the Absorption Plant are dried in the Dehydration Units before distribution through pipelines to existing markets.

The heavier sweet gases from the Absorption Plant are fed to the Liquefiable Petroleum Gases (LPG) Plant where propane butane and heavier hydrocarbon condensates are separated for subsequent distribution by rail, truck or pipelines.

B. WATERTON GAS PLANT (SHELL CANADA RESOURCES LIMITED)

The Waterton Gas Plant, illustrated in Figure 3.3, consists of two parallel operations as indicated in Figures 3.4 and 3.5.

Plant No. 1 was started up in January 1962 with a rated sales gas capacity of 120 MMCF/D. Expansion of the facility in 1967 increased production capabilities to 170 MMCF/D of sales gas. An additional output of 141 MMCF/D of sales gas became available with the commissioning of Plant No. 2 in 1971.

The Waterton Gas Plant was designed to handle up to 473 MMCF/D of raw natural gas from some 15 producing wells in the Waterton Gas Field which was discovered by Shell Resources Limited in 1957. The raw sour gas fed to the plant contains up to 17% hydrogen sulfide (H_2S) plus some carbon dioxide (CO_2). The "wet" inlet stream enters the plant by way of the slug catcher at a pressure of 1050 psig (7,250 kilopascals). Here,

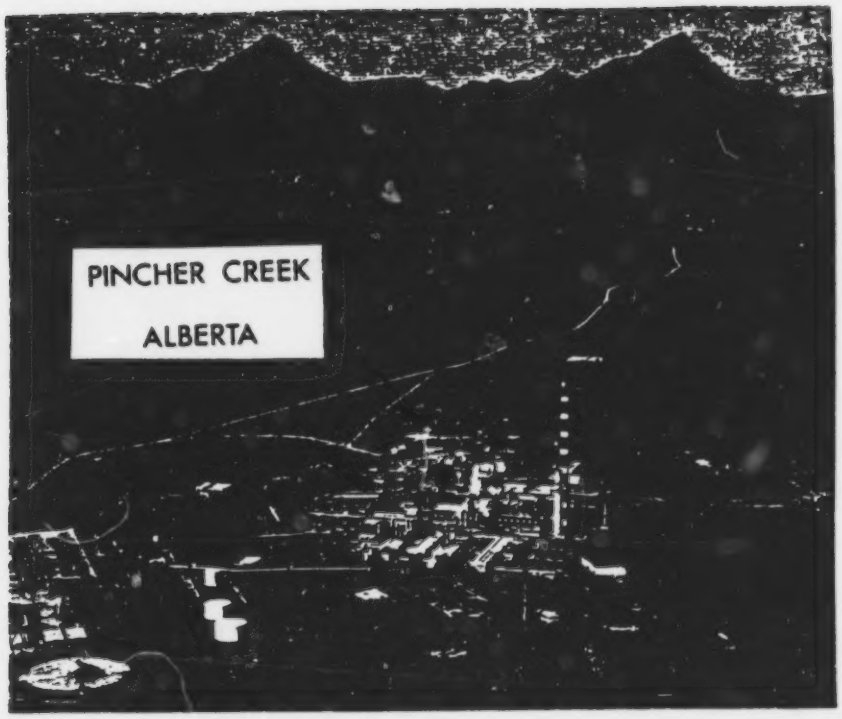


Figure 3.3 Shell Canada Resources Limited Waterton Gas Plant at Pincher Creek, Alberta.

the entrained hydrocarbon liquids and water of condensation are separated from the gas by gravity.

The deliquified sour gas leaving the slug catcher is directed to Absorption Units (#1 and #2) by way of the paths a1 and a2 shown in Figure 3.4. A light oil circulating in a closed loop system operating at a pressure of 1,000 psig (6,900 kilopascals), is used to remove the butane, pentane, and propane fractions from the main gas stream. After separation of the butanes and pentanes from the circulating light oil is accomplished by boiling, these products are transferred to Gasoline Stabilization and Desulfurization Units (#3 and #4) by way of paths b1 and b2.

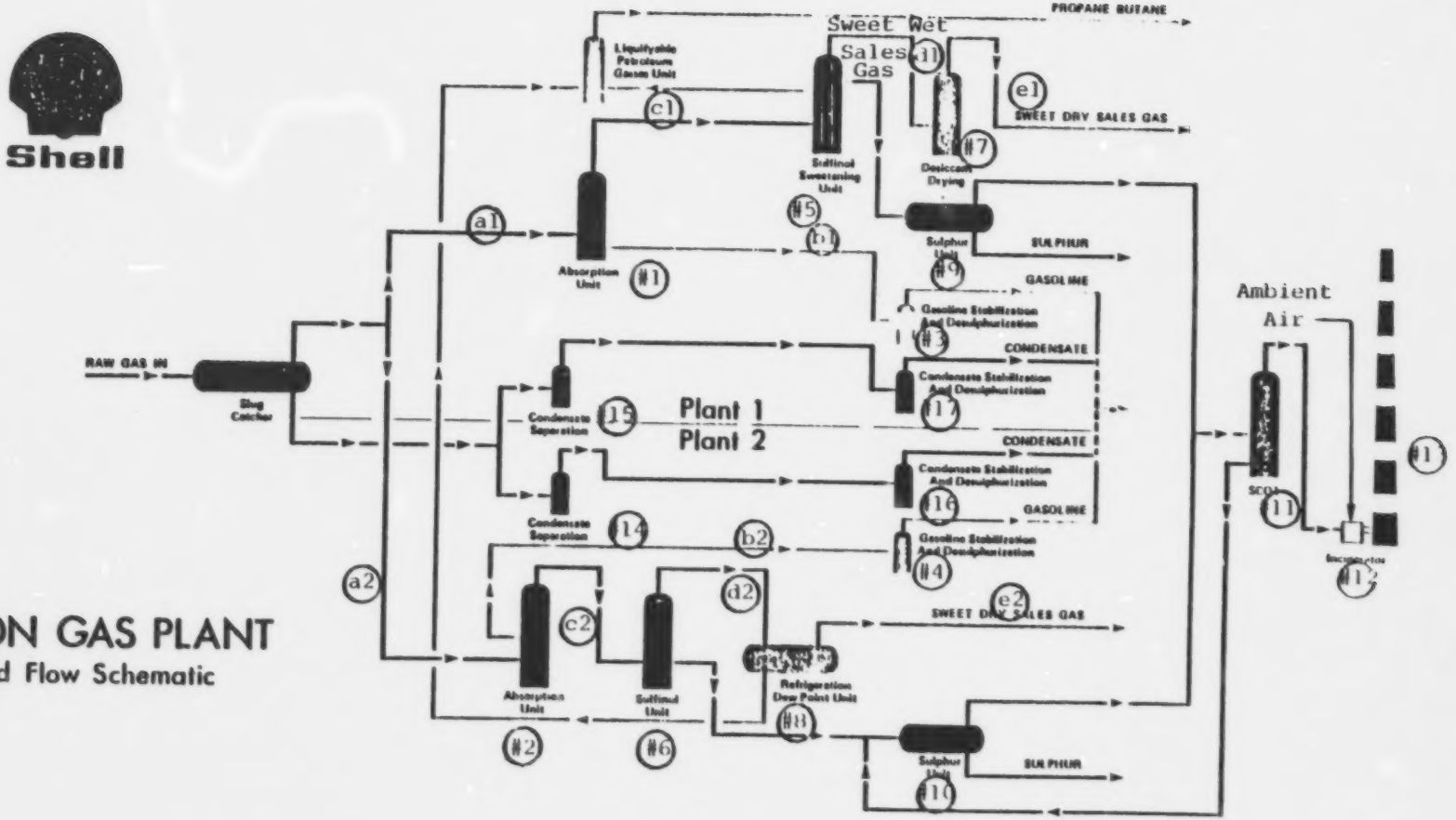


Figure 3.4 Simplified Flow Schematic for Waterton Gas Plant

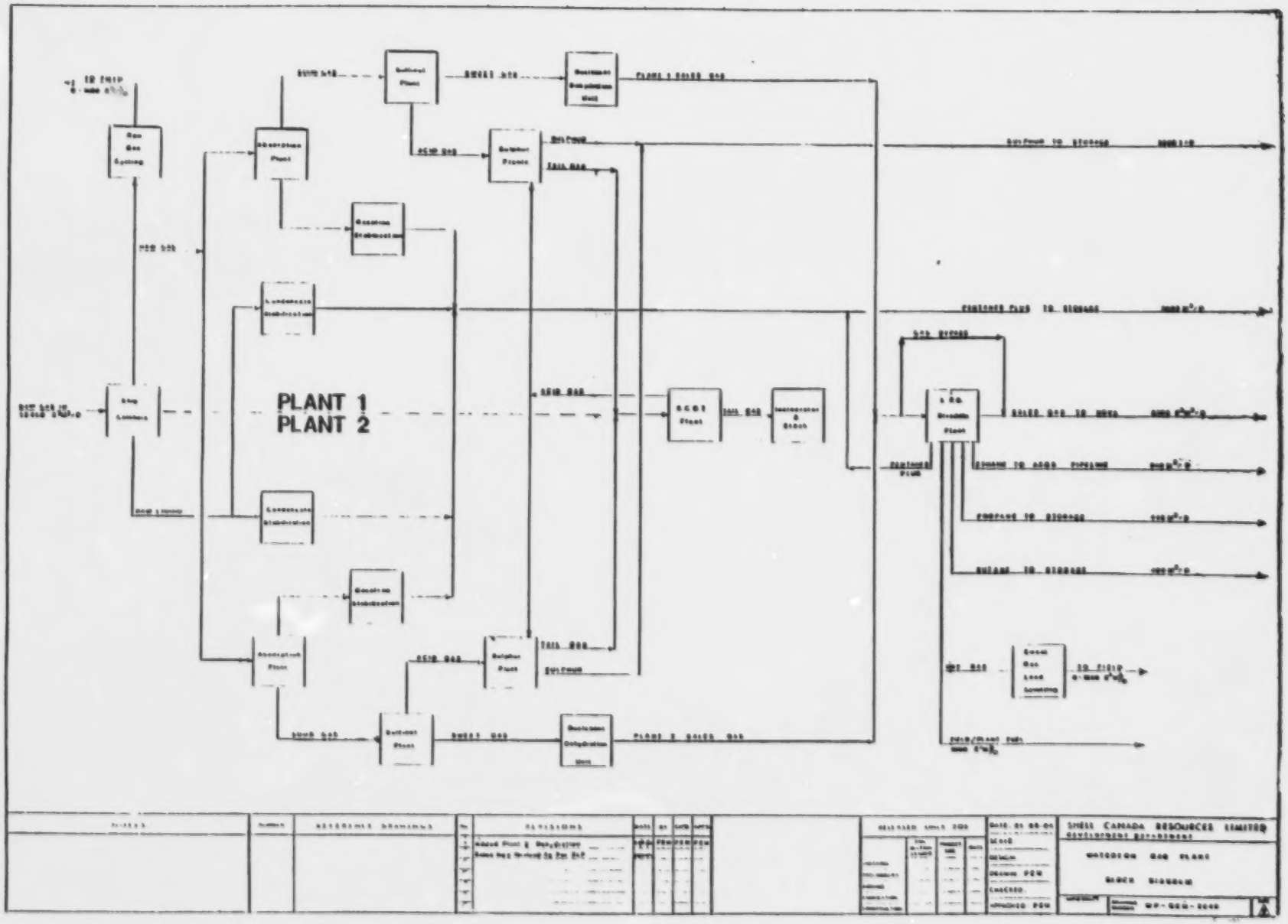


Figure 3.5 Waterton Gas Plant Block Diagram

The main gas streams leaving the Absorption Units (#1 and #2) travel to the Sulfinol Units (#5 and #6) along routes c1 and c2 for sweetening through removal of hydrogen sulfide (H_2S) and carbon dioxide (CO_2). The sweetening (Sulfinol) process involves contacting the sour gas stream with a proprietary Shell development solvent called sulfolane (thiocyclopentane 1,1-dioxide). This highly efficient gas absorption step produces a sweet wet gas still containing some propane as well as light hydrocarbons but negligible hydrogen sulfide (H_2S). The water vapor picked up during sweetening must be removed before the gas can be sold.

In Plant No. 1, the sweet wet gas is dried in a Dessicant Type Regenerative Dryer (Unit #7) where the water vapor is removed by adsorption on porous surfaces. Prior to 1982 drying of the sweet wet gas leaving Plant No. 2, Sulfinol Unit (#6) was accomplished by cooling the stream to -20°F (-29°C) in the Refrigeration Dew Point Unit (#8). The Refrigeration Dew Point Unit has now been replaced with Dessicant Dehydrator.

The sweet dry sales stream containing less than 5 lb. of water vapor per million cubic feet of gas is distributed by pipeline to Eastern Canada and the United States.

Regeneration of spent Sulfinol solutions (Units #5 and #6) involves removal of the acid gases (H_2S and CO_2) through distillation with subsequent transfer of the recovered hydrogen sulfide (H_2S) to the Claus Sulfur Units (#9 and #10). The Claus process is designed to convert roughly one-third of the hydrogen

sulfide (H_2S) to sulfur dioxide (SO_2) according to the reaction.

$$H_2S(g) + 1\ 1/2\ O_2\ (g) \longrightarrow H_2O(g) + SO_2(g)$$

The remainder of the H_2S is reacted with the produced SO_2 in a catalyst bed at temperatures of 500-750°F to produce elemental sulfur according to the scheme.

$$2H_2S(g) + SO_2(g) \longrightarrow 2H_2O(1) + 3\ S(1)$$

The gaseous sulfur is condensed and poured to form solid storage piles. When needed, the sulfur can be shipped out of the plant by rail in the form of slates or prills.

Under optimum operating conditions the Claus Sulfur Units (#9 and #10) are capable of converting 96% of the entering hydrogen sulfide (H_2S) to elemental liquid sulfur (S). Emissions of hydrogen sulfide (H_2S) to the environment are minimized by further processing of the gas streams leaving the Claus Units (#9 and #10) in the catalytic Shell Claus Off-Gas Treating (SCOT) plant (#11) which is designed to provide a 98.7% overall recovery of sulfur from the original raw gas stream. Residual levels of hydrogen sulfide (H_2S) are converted to sulfur dioxide in the Incinerator (#12) before the processed gas is exhausted through the 500 foot (152 meter) stack (#13).

The hydrocarbon liquids, that were originally separated from the incoming wet sour gas in the Slug Catcher, are treated

in Condensate Separation Units (#14 and #15) before they are stabilized (Units #16 and #17) prior to pipeline shipment.

Liquified Petroleum Gases (L.P.G.) recovered during the sweetening (#5 and #6) and stabilization (#8) processes, are treated in the Liquefiable Petroleum Gases Unit (#18) with eventual separation into propane and butane.

IV SAMPLE RECOVERY

Quantitative recovery of the samples from all parts of the train required a rigorous and meticulous procedure which took 3 to 4 hours to complete. There was no visual evidence of recognizable accumulation of gas hydrates in any part of the sampling system.

A. INTRODUCTION

Upon completion of a test at each sampling site, Valves (1 and 3), shown in Figure 2.3, were closed to stop sample flow through the collection system. Residual Hydrogen Sulfide (H_2S) was purged from the sampling train components by opening Pressure Reducing Valve (B) and Valve (4) to provide a flow of nitrogen through the system for 30 minutes. At the end of this time period Pressure Reducing Valve (B) and Valves (4 and 5) were closed. The degassed sampling train was then disconnected from the Process Line Reducing Valve (A) and Exhaust to the Flare (C) for sample recovery from each of the sampling train components.

Figure 4.1 illustrates sample and blank recovery procedures.

B. SAMPLING LINE WASHES

For cleanup purposes, the sampling line and filter holder were removed from the Steam Chest.

1. Sampling Line - Filter Holder

The inside of the sampling line and filter holder were rinsed with 6 M nitric acid from a polyethylene wash bottle, into

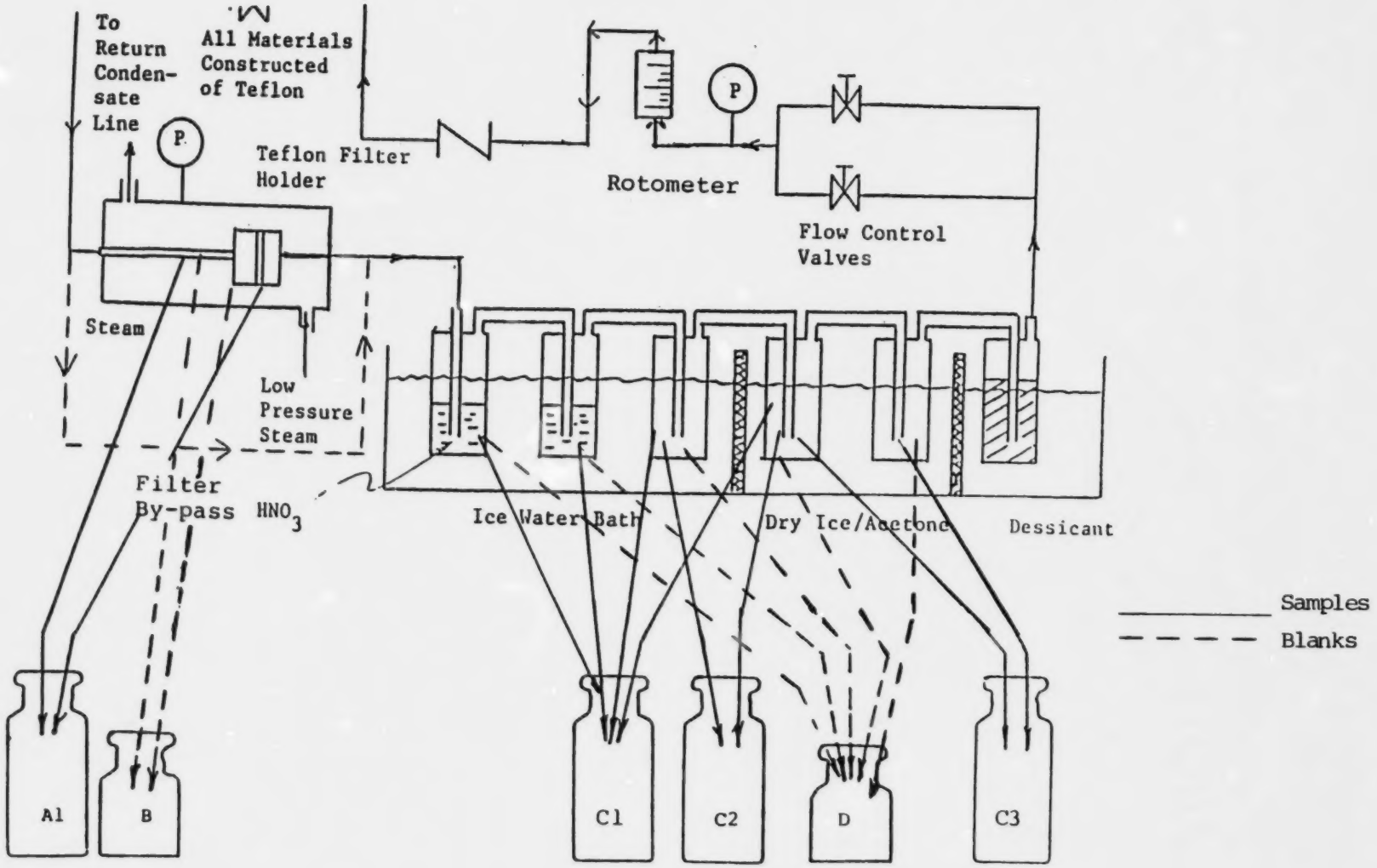


Figure - 4.1 Sample and Blank Recovery Procedure

a labelled 500 mL sample bottle A1. Washing was continued until visual inspection confirmed that all surfaces were free of particulate matter. The well sealed bottle A1 was carefully stored after the liquid level had been marked. The sampling line and filter holder were rinsed with deionized distilled water, which was discarded, before storage for the next test.

2. Sampling Line - Filter Holder Blanks

Prior to the next test, the sampling line and filter holder were rinsed with 0.1 M nitric acid which was collected in labelled container B. This blank served as a test for gross contamination that might occur during storage and/or shipment between tests. After the liquid level was marked, container B was stored for subsequent trace element analysis. The sampling line and filter holder were rinsed with distilled water before assembly into the Steam Chest for the upcoming test.

C. COMBINED IMPINGER TRAIN

Sample recovery was accomplished after removing the impingers individually from the ice-water and dry ice-acetone baths.

1. Moisture Determination

After liquid film and drops were wiped from the outside walls of each impinger with absorbent paper, they were weighed to the nearest $\pm$0.1 g on a trip balance for determination of process

stream moisture content according to the condensation method (AERM-3)(4). The dessicant in impinger 6 was discarded after weighing.

2. Impingers 1,2,3,4 and 5

The contents of impingers 1,2,3,4 and 5 were emptied into 500 mL labelled containers C1,C2 and C3 if required. Each impinger top and bottom was rinsed with 20-30 mL of 6 M nitric acid with the rinses being added to sample bottles C1,C2 and C3. Washing was continued until the surfaces were visually clean.

3. Impinger Blanks

Before the next test approximately 25 mL of 0.1 M nitric acid were poured into each impinger which was shaken vigorously for 2 to 3 minutes. These washes were collected in labelled container D to serve as a blank for the upcoming sampling program. This procedure provided a check on possible gross contamination during storage and/or shipment between tests.

Finally, each impinger was flushed with deionized distilled water which was discarded.

After approximately 100 mL of 6 M HNO_3 had been poured into impingers 1 and 2 and 250 g of dessicant were added to impinger 6, all impingers were weighed and assembled for use in the next test.

4. Teflon Connectors

The Teflon connectors between individual impingers were rinsed with 6 M nitric acid into sample bottles C1,C2 and C3.

They were ready for the assembly of the impinger train after a final rinse with deionized distilled water which was discarded.

V ANALYTICAL PROCEDURES

The analytical procedures developed for earlier studies (1,2) were applied to the samples collected during this investigation. Atomic absorption spectrometry (AAS) offered the most viable approach to the measurement of the 29 trace elements of concern. Generally, atomic absorption is relatively interference free, however, high concentrations of dissolved salts can produce interference by scattering, particularly when analyses are carried out at UV wavelengths. Although atomic absorption is normally not a sensitive technique for arsenic, selenium and mercury determinations, modification of the standard procedures can lower detection limits by 2 orders of magnitude. For example, furnace techniques can be used to improve analyses for selenium, arsenic and vanadium. The cold vapour procedure has been reported to be a reliable method of determining trace amounts of mercury (3,7,8).

To ensure complete dissolution of all but the most inert metallic species that were collected as particulate matter, it would be desirable to use a mixture of nitric and hydrochloric acids for preparation of the solutions to be subjected to atomic absorption spectrometry. However, the use of hydrochloric acid must be limited to prevent significant losses of the volatile halides of arsenic, selenium and vanadium during the evaporation of excess acid. Consequently, all sample preparation was done in parallel to provide one group of metals in nitric acid and

another in hydrochloric acid. Table 5.1 details the selection of acids for the dissolution of the metals pertinent to this investigation. Also provided are the analytical parameters for atomic absorption analyses.

A. PLANT TESTS

All test liquid catches were treated according to the flowsheet illustrated in Figure 5.1. The combined volume of impingers 1,2,3,4 and 5 was reduced to 100 mL by evaporation. Aliquots of the sample line and filter holder washes and of the concentrated impinger contents and washes were treated according to the procedures detailed in Figure 5.1.

The preparation of solution blanks is illustrated in Figure 5.2. Because of the potential for interferences and matrix effects to be created as a result of the complexity of the solutions being analyzed, it was essential to determine the recovery of each metal species by creating synthetic systems of known composition of each of the 29 elements under investigation. Distilled water samples were spiked with appropriate volumes of the 1000 ppm AA standards according to the schemes illustrated in Table 5.2. The preparations of solutions for the liquid recoveries are illustrated in Figure 5.3. All solutions corresponding to final tests, blanks and recoveries were treated similarly with respect to the evaporation and dilution steps described previously(1).

Table 5.1 Summary of Analytical Parameters for Atomic Absorption Analysis

Element		Analytical Wavelength	Detection Limit (mg/L)	Sensitivity (mg/L)	Flame Type	Optimum Concentration Range (mg/L)	Acid Prep	Comments
Ag	Silver	3281	0.05	0.03	A-Ac	0.1-2.0	HNO_3	
Al	Aluminum	3093	1.0	0.4	N-Ac	5.0-100	HCl	Add 2000 ppm K
As	Arsenic	1937	0.005	0.005	furnace	0.005-0.05	HNO_3	
B	Boron	2497	10	9	N-AC	50-500	HNO_3	
Be	Beryllium	2349	0.02	0.01	N-AC	0.1-2.0	HCl	Add 5% 8-hydroxy-quinoline
Cd	Cadmium	2288	0.02	0.01	A-AC	0.1-2.0	HNO_3	
Co	Cobalt	2407	0.2	0.05	A-AC	0.5-10	HCl	
Cu	Copper	3247	0.1	0.03	A-AC	0.5-10	HNO_3	
Cr	Chromium	3579	0.2	0.06	N-AC	0.5-10	HNO_3	
Fe	Iron	2483	0.1	0.04	A-AC	0.5-10	HNO_3	
Ga	Gallium	2874	2.0	1.5	N-AC	5-100	HNO_3	Add 2000 ppm K
Ge	Germanium	2651	2.0	1.0	N-AC	5-100	HNO_3	
Hg	Mercury	2537	0.01	0.01	Cold vapor	0.01-0.1	Special prep	
In	Indium	3040	1.0	0.2	N-AC	5.0-100	HNO_3	Add 2000 ppm K
Li	Lithium	6708	0.05	0.02	N-AC	0.1-2.0	HCl	Add 2000 ppm K
Mn	Manganese	2795	0.05	0.02	A-AC	0.1-2.0	HNO_3	
Mo	Molybdenum	3133	0.5	0.2	N-AC	1.0-20	HNO_3	Add 1000 ppm Al
Ni	Nickel	2320	0.2	0.06	A-AC	0.5-10	HNO_3	
Pb	Lead	2170	0.2	0.1	A-AC	0.5-10	HNO_3	
Sb	Antimony	2176	0.4	0.2	A-AC	1.0-20	HCl	
Sc	Scandium	3912	0.5	0.1	N-AC	2.0-50	HCl	Add 2000 ppm K
Se	Selenium	1960	0.01	0.01	Furnace	0.01-0.05	HNO_3	
Sn	Tin	2355	1.0	1.0	N-AC	5.0-100	HCl	
Sr	Strontium	4607	0.05	0.1	N-AC	0.1-2.0	HNO_3	Run by emission add 2000 ppm K
Te	Tellurium	2143	0.5	0.2	A-AC	1.0-2.0	HNO_3	
Ti	Titanium	3643	1.0	1.0	N-AC	10-200	HCl	Add 2000 ppm Al
Tl	Thallium	2768	0.5	0.1	A-AC	1.0-20	HNO_3	
V	Vanadium	3185	0.02	0.01	Furnace	0.05-0.5	HNO_3	
Zn	Zinc	2138	0.03	0.01	A-AC	0.1-2.0	HCl	

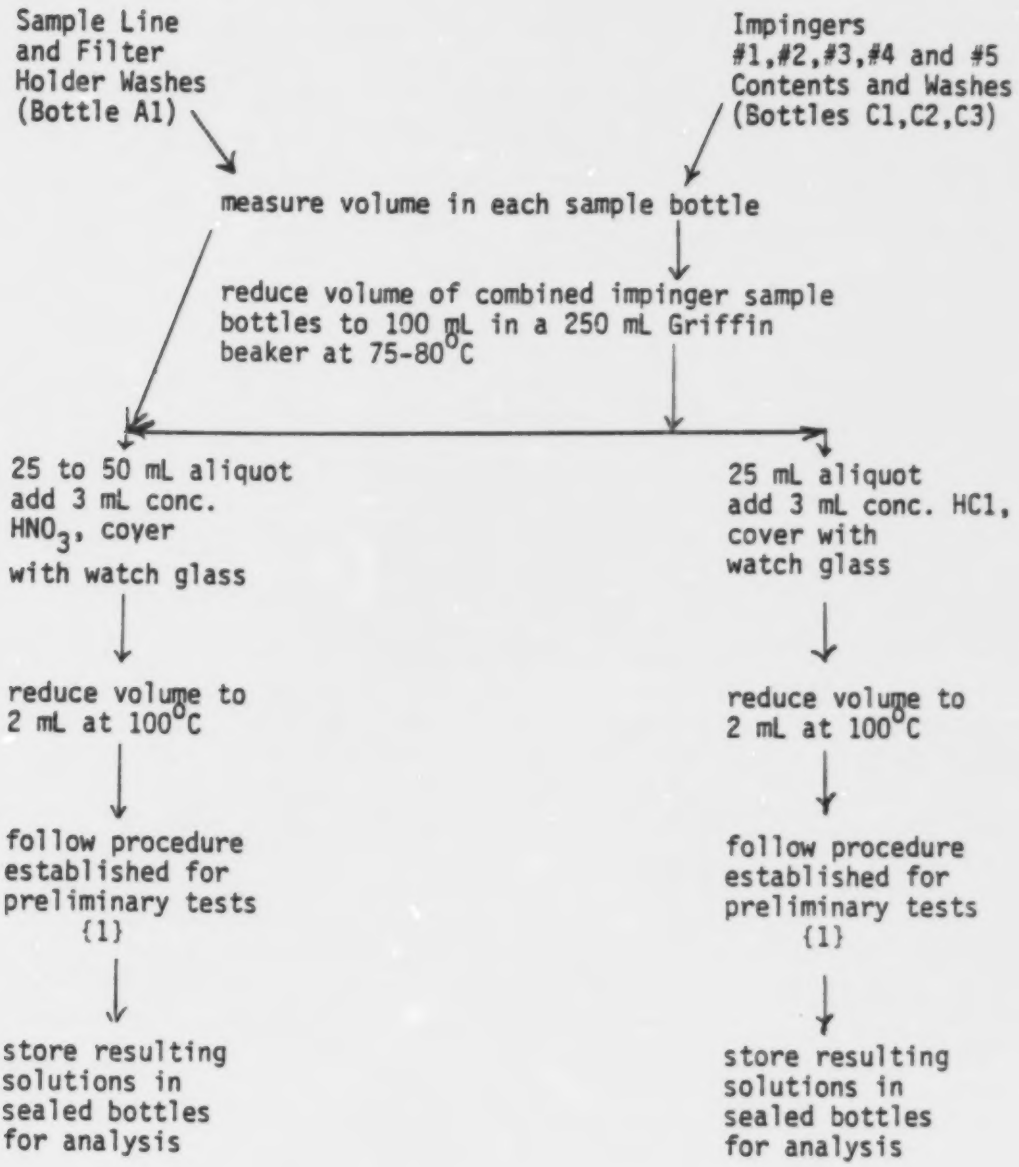
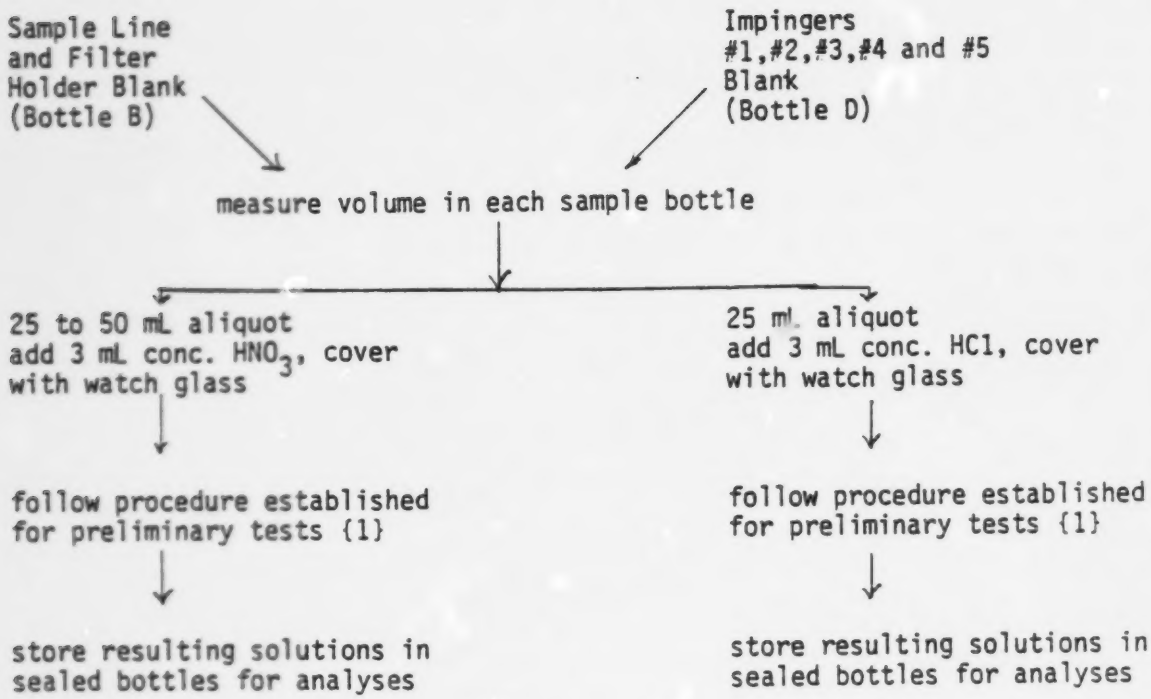


Figure 5.1: Treatment of Solutions From Plant Tests



Storage Bottles Polyethylene with Polyethylene Caps

Figure 5.2: Preparation of Blanks for Solution Analyses

Table 5.2 Amounts of Standards Added to Solutions for Recoveries Using 1000 ppm Standards

HNO_3 TREATMENT		HCl TREATMENT	
Element	Amount Added uL	Element	Amount Added uL
Mn	25	Ti	2000
Ni	100	Co	100
Cu	100	Zn	25
Ga	1000	Sb	200
Ge	1000	Be	25
Mo	200	Al	1000
Cd	25	Sn	1000
Pb	100	Li	25
Sr	50	Sc	200
B	5000		
Ag	100		
Tl	200		
In	1000		
Te	500		
Fe	100		
As	100 of 10 ppm		
Se	100 of 10 ppm		
V	10		
Hg	50		
Cr	100		

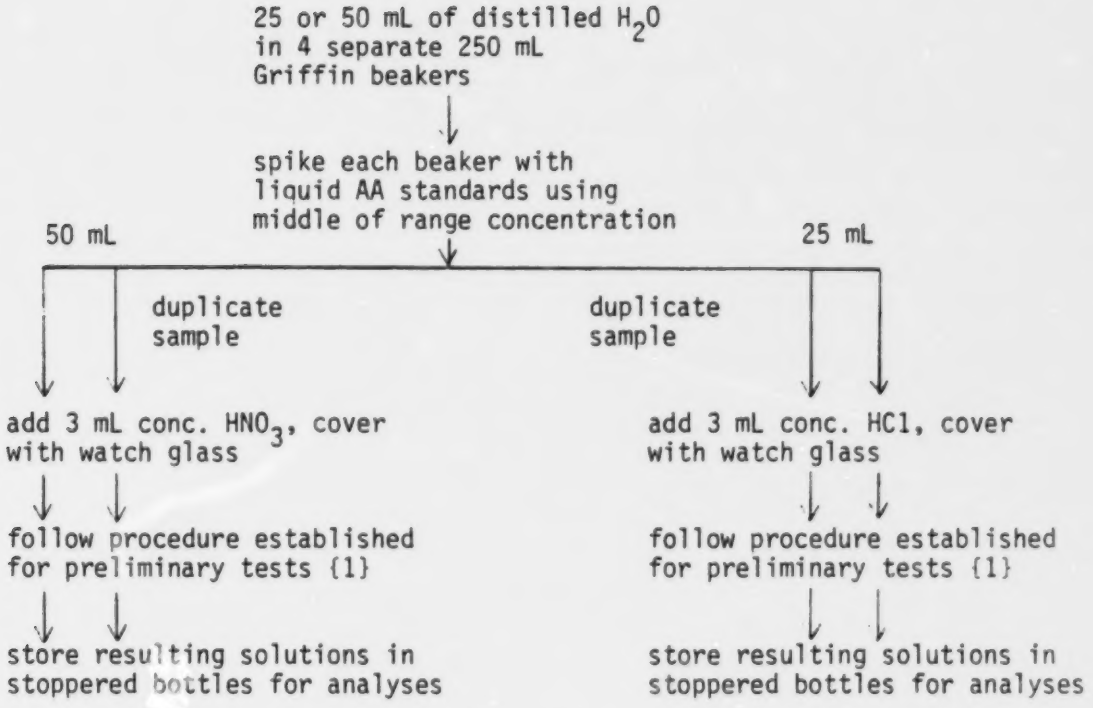


Figure 5.3: Preparation of Solutions for Component Recoveries From Solutions

B. ATOMIC ABSORPTION SPECTROMETRY

Atomic absorption analyses were carried out with an Instrumentation Laboratory Model IL 551 Video I double beam atomic absorption/atomic emission spectrophotometer with microcomputer, cathode-ray tube display. Flameless analyses were performed using a Varian Model 975 spectrophotometer equipped with a Varian temperature controlled furnace Model GTA95. The instruments were equipped to use air/acetylene, nitrous oxide/acetylene, or argon/hydrogen flames depending on the element being investigated. Table 4.1 summarizes the flame types for each element.

Limits of detection of each metal in mg/L were established by analyzing the lowest standard 10 times in order to determine the mean value of the absorbance and the standard deviation in terms of absorbance. Each detection limit shown in Table 4.1 was evaluated according to the expression:

$$\text{Detection Limit (mg/L)} = 2 \times \frac{\text{standard deviation (absorbance units)}}{\text{mean of 10 runs (absorbance units)}} \times \text{standard concentration (mg/L)}$$

Calibration curves were prepared by running all standards except the lowest ones twice each. Analyses of samples, blanks and recoveries were followed by running of the standards twice if less than 10 samples were being handled. Standards were checked every 10 samples when large numbers of samples were being processed.

Figure 5.4 illustrates the procedures adopted for atomic absorption spectrometric determination of the trace metals under consideration.

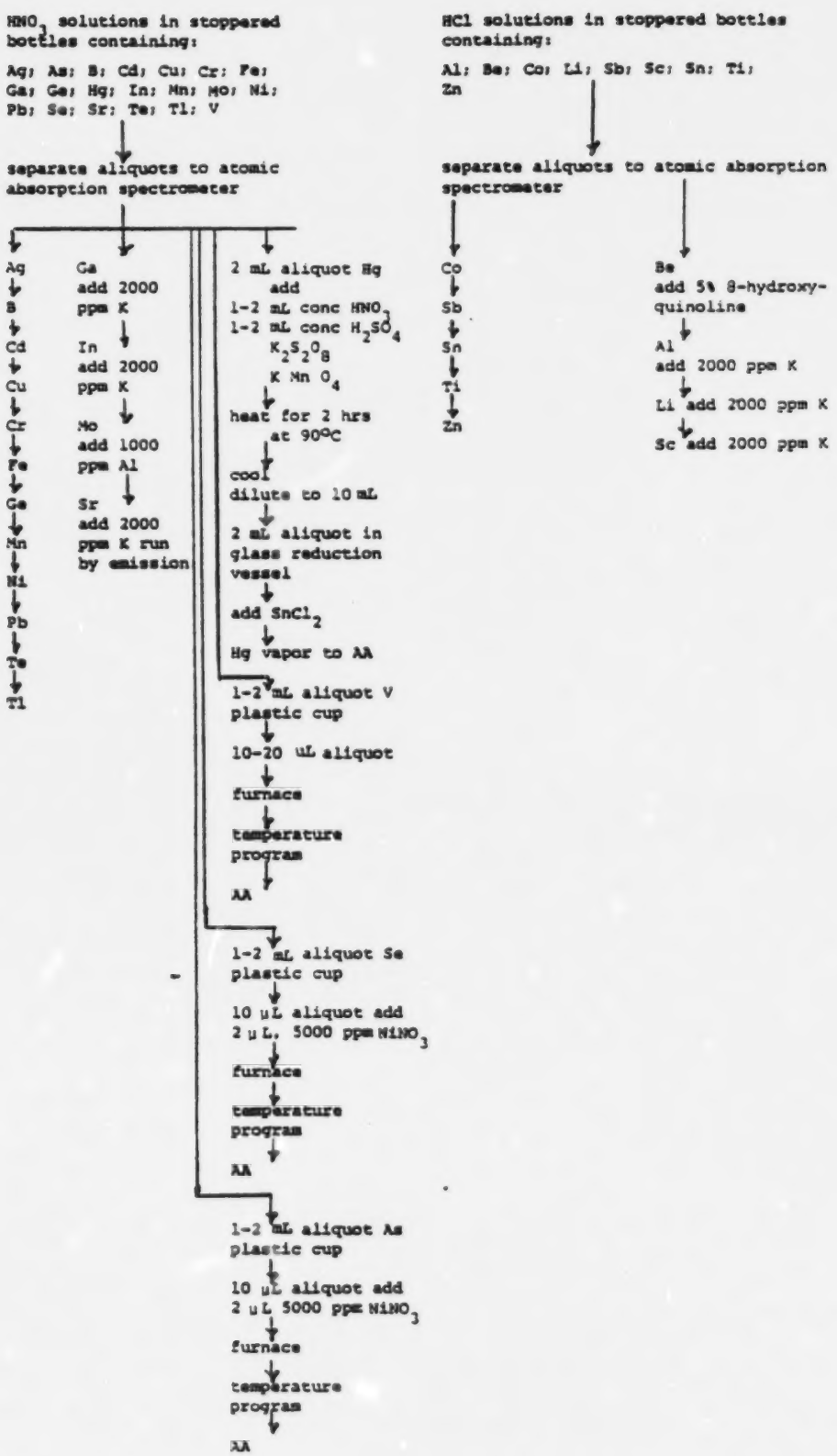


Figure 5.4 Treatment of HNO_3 and HCl Solutions for Atomic Absorption Spectrometry

VI RESULTS

Comprehensive pre-sampling investigations during an earlier study (1) indicated that meaningful results could be obtained only with pre-concentration of field blanks and liquids recovered from impingers and cold traps. Impinger catches, normally amounting to 700 to 1000 mL were pre-concentrated to 100 mL before 25 mL aliquots were taken for analysis. Sampling line and filter holder washes were not pre-concentrated because these liquid volumes were generally less than 150 mL.

Table 6.1 summarizes the laboratory recoveries of the 29 metals from spiked liquid samples.

In this section of the report a metal is considered to be present in a stream entering or leaving any unit if the element was "detected" above the limit of detection (LOD) in the sampling line or impinger component of the sampling train. The trace element concentrations of metals whose presence was "detected" have been evaluated by using the measured elemental concentrations and values corresponding to the limits of detection (LOD) for the two samples recovered from the sampling train for each test.

A. PINCHER CREEK GAS PLANT (GULF)

The results of the testing program at the Pincher Creek Gas Plant are summarized in Tables 6.2 to 6.20. The order of data presentation is consistent with sampling site identification in

Table 6.1 Per Cent Recoveries of Metals From Spiked Liquids During 1983 Analytical Period

		Test #1 5/18 - 6/10		Test #2 6/16 - 6/24		Test #3 6/30 - 7/11		
		#1	#2	#1	#2	#1	#2	Average
Ag	Silver	50	15	60	85	n.s	n.s	53±29
Al	Aluminum	90	95	110	110	103	98	102± 7
As	Arsenic	110	115	85	85	115	100	102±14
B	Boron	*	*	105	105	98	98	102± 4
Be	Beryllium	94	93	100	106	100	100	97± 3
Cd	Cadmium	98	100	100	100	96	96	98± 2
Co	Cobalt	93	95	108	103	108	103	102± 6
Cr	Chromium	100	105	110	110	125	125	113±10
Cu	Copper	95	void	105	105	105	105	103± 4
Fe	Iron	125	95	120	120	105	105	112±12
Ga	Gallium	90	90	95	95	100	105	96± 6
Ge	Germanium	95	95	60	95	80	85	85±14
Hg	Mercury	n.s	n.s	100	97	86	76	90±11
In	Indium	95	100	110	100	110	110	104± 6
Li	Lithium	96	100	100	100	114	95	101± 7
Mn	Manganese	109	105	102	102	98	98	102± 4
Mo	Molybdenum	98	95	**220	123	130	130	112±16
Ni	Nickel	100	100	105	105	100	100	100± 3
Pb	Lead	95	100	104	104	100	60	94±17
Sb	Antimony	138	146	106	106	88	68	109±30
Sc	Scandium	82	82	115	115	60	69	87±23
Se	Selenium	115	105	60	void	85	60	85±25
Sn	Tin	123	118	105	108	88	178	120±31
Sr	Strontium	84	94	120	120	118	122	110±16
Te	Tellurium	99	100	100	100	98	97	99± 1
Ti	Titanium	69	68	106	103	61	66	79±20
Tl	Thallium	88	93	100	98	95	100	96± 5
V	Vanadium	175	175	125	125	110	160	145±28
Zn	Zinc	104	100	93	93	119	106	103±10

n.s - not spiked
* - spiked with bad standard
** - possible double spike

Table 6.2 Metal Concentrations in Amine Contactor Inlet Stream at the Gulf-Pincher Creek Gas Plant During Test #1

Source: Gulf-Pincher Creek Contactor Inlet Test No: 1 Date: March 30, 1983

Sample Analyses	Micrograms Probe	Micrograms Impingers	Total Elemental Weight ug	Elemental Concentration ug/rcf
Ag Silver	3.8	5.5	9.3	0.024
Al Aluminum	76.0	330.	400.	1.1
As Arsenic	0.76	19.0	19.0	0.051
B Boron	1500	2200	3700	9.8
Be Beryllium	2.3	3.3	5.6	0.015
Cd Cadmium	19.0	270.	290.	0.77
Co Cobalt	15.0	22.0	37.0	0.098
Cr Chromium	15.0	87.0	100.0	0.27
Cu Copper	15.0	500.	520.	1.4
Fe Iron	250.	12000	12000	32.0
Ga Gallium	150.	220.	370.	0.98
Ge Germanium	150.	220.	370.	0.98
Hg Mercury	0.76	1.1	1.9	0.005
In Indium	76.0	110.	190.	0.49
Li Lithium	3.8	5.5	9.3	0.02
Mn Manganese	6.8	230.	240.	0.62
Mo Molybdenum	38.0	55.0	93.0	0.25
Ni Nickel	15.0	240.	260.	0.68
Pb Lead	15.0	320.	330.	0.88
Sb Antimony	38.0	55.0	93.0	0.25
Sc Scandium	38.0	55.0	93.0	0.25
Se Selenium	0.76	1.1	1.9	0.005
Sn Tin	76.0	110.	190.	0.49
Sr Strontium	3.8	5.5	9.3	0.024
Te Tellurium	38.0	55.0	93.0	0.25
Ti Titanium	76.0	110.	190.	0.49
Tl Thallium	38.0	55.0	93.0	0.25
V Vanadium	1.5	11.0	12.0	0.033
Zn Zinc	43.0	2100	2100	5.6

All elements except those in boxes ☐ are below the limit of detection

Table 6.3 Metal Concentrations in Amine Contactor Inlet Stream at the Gulf-Pincher Creek Gas Plant During Test #2

Source: Gulf-Pincher Creek Contactor Inlet | Test No: 2 | Date: March 31, 1983

Sample Analyses	Micrograms Probe	Micrograms Impingers	Total Elemental Weight ug	Elemental Concentration ug/rcf
Ag Silver	3.8	5.3	9.0	0.024
Al Aluminum	75.0	110.	180.	0.48
As Arsenic	0.38	3.2	3.5	0.009
B Boron	1500	2100	3600	9.5
Be Beryllium	1.5	2.1	3.6	0.010
Cd Cadmium	1.5	13.0	14.0	0.037
Co Cobalt	7.5	11.0	18.0	0.048
Cr Chromium	15.0	130.	140.	0.37
Cu Copper	7.5	53.0	60.0	0.16
Fe Iron	53.0	43000	43000	110.
Ga Gallium	150.	210.	360.	0.95
Ge Germanium	150.	210.	360.	0.95
Hg Mercury	0.75	1.1	1.8	0.005
In Indium	75.0	110.	180.	0.48
Li Lithium	3.8	5.3	9.0	0.024
Mn Manganese	3.8	220.	220.	0.59
Mo Molybdenum	15.0	21.0	36.0	0.095
Ni Nickel	15.0	230.	250.	0.65
Pb Lead	15.0	32.0	47.0	0.12
Sb Antimony	30.0	42.0	72.0	0.19
Sc Scandium	38.0	53.0	90.0	0.24
Se Selenium	0.75	1.1	1.8	0.005
Sn Tin	150.	210.	360.	0.95
Sr Strontium	3.8	5.3	9.0	0.024
Te Tellurium	38.0	53.0	90.0	0.24
Ti Titanium	75.0	110.	180.	0.48
Tl Thallium	38.0	53.0	90.0	0.24
V Vanadium	3.8	5.3	9.0	0.024
Zn Zinc	6.0	3500	3500	9.2

All elements except those in boxes ☐ are below the limit of detection

Table 6.4 Metal Concentrations in Amine Contactor Inlet Stream at the Gulf-Pincher Creek Gas Plant During Test #3

Source: Gulf-Pincher Creek Contactor Inlet | Test No: 3 | Date: March 31, 1983

Sample Analyses	Micrograms Probe	Micrograms Impingers	Total Elemental Weight - ug	Elemental Concentration ug/dscf
Ag Silver	7.3	6.3	14.3	0.0531
Al Aluminum	66.0	90.0	160.	0.62
As Arsenic	0.38	0.54	0.92	0.004
B Boron	920.	900.	1800	7.2
Be Beryllium	1.3	1.8	3.1	0.012
Cd Cadmium	1.3	6.4	7.7	0.03
Co Cobalt	13.0	18.0	31.0	0.12
Cr Chromium	13.0	36.0	49.0	0.19
Cu Copper	6.6	9.0	16.0	0.061
Fe Iron	200	420	620	2.4
Ga Gallium	130.	180.	310.	1.2
Ge Germanium	130.	180.	310.	1.2
Hg Mercury	2.0	3.6	5.6	0.022
In Indium	66.0	90.0	160.	0.62
Li Lithium	3.3	5.4	8.7	0.034
Mn Manganese	3.3	23.0	27.0	0.11
Mo Molybdenum	13.0	18.0	31.0	0.12
Ni Nickel	13.0	120	130.	0.51
Pb Lead	13.0	18.0	31.0	0.12
Sb Antimony	27.0	45.0	71.0	0.28
Sc Scandium	33.0	54.0	87.0	0.34
Se Selenium	0.66	0.90	1.6	0.006
Sn Tin	66.0	90.0	160.	0.62
Sr Strontium	3.3	5.4	8.7	0.034
Te Tellurium	33.0	54.0	87.0	0.34
Ti Titanium	66.0	90.0	160.	0.62
Tl Thallium	33.0	54.0	87.0	0.34
V Vanadium	3.3	6.3	9.6	0.038
Zn Zinc	5.3	610	620	2.4

All elements except those in boxes ☐ are below the limit of detection

Table 6.5 Metal Concentrations in Amine Contactor Outlet Stream at the Gulf-Pincher Creek Gas Plant During Test #1

Source: Gulf - Pincher Creek Contactor Outlet Test No: 1 Date: March 29, 1983

Sample Analyses	Micrograms Probe	Micrograms Impingers	Total Elemental Weight ug	Elemental Concentration ug/rcf
Ag Silver	4.8	5.4	10.0	0.02
Al Aluminum	95.0	470.	570.	1.3
As Arsenic	2.8	2.4	5.1	0.011
B Boron	1900	2200	4100	9.2
Be Beryllium	2.9	3.4	6.2	0.014
Cd Cadmium	3.8	6.8	11.0	0.024
Co Cobalt	19.0	20.0	39.0	0.088
Cr Chromium	19.0	20.0	39.0	0.088
Cu Copper	67.0	120.	190.	0.42
Fe Iron	1500	1100	2700	6.0
Ga Gallium	190.	200.	390.	0.88
Ge Germanium	190.	200.	390.	0.88
Hg Mercury	0.95	1.4	2.3	0.005
In Indium	95.0	140.	230.	0.51
Li Lithium	4.8	5.4	10.0	0.02
Mn Manganese	15.0	26.0	41.0	0.09
Mo Molybdenum	48.0	54.0	100.	0.23
Ni Nickel	19.0	68.0	87.0	0.19
Pb Lead	19.0	34.0	53.0	0.12
Sb Antimony	48.0	54.0	100.	0.23
Sc Scandium	48.0	54.0	100.	0.28
Se Selenium	0.95	1.4	2.3	0.005
Sn Tin	95.0	140.	230.	0.51
Sr Strontium	4.8	5.4	10.0	0.023
Te Tellurium	48.0	54.0	100.	0.28
Ti Titanium	95.0	140.	230.	0.51
Tl Thallium	48.0	54.0	100.	0.28
V Vanadium	1.9	2.0	3.9	0.009
Zn Zinc	100.	1500	1600	3.5

All elements except those in boxes ☐ are below the limit of detection

Table 6.6 Metal Concentrations in Amine Contactor Outlet Stream at the Gulf-Pincher Creek Gas Plant During Test #2

Source: Gulf - Pincher Creek Contactor Outlet Test No: 2 Date: March 29, 1983

Sample Analyses	Micrograms Probe	Micrograms Impingers	Total Elemental Weight ug	Elemental Concentration ug/rcf
Ag Silver	5.8	5.1	11.0	0.024
Al Aluminum	120.	[86.0]	[200.]	[0.45]
As Arsenic	[4.7]	0.51	[5.2]	[0.012]
B Boron	2300	2600	4900	11.0
Be Beryllium	2.3	2.6	4.9	0.011
Cd Cadmium	[10.0]	2.6	[13.0]	[0.029]
Co Cobalt	12.0	8.6	20.0	0.05
Cr Chromium	23.0	26.0	49.0	0.11
Cu Copper	12.0	8.6	20.0	0.05
Fe Iron	[3000]	[270.]	[3300]	[7.3]
Ga Gallium	230.	260.	490.	11.0
Ge Germanium	230.	260.	490.	11.0
Hg Mercury	1.2	0.86	2.0	0.005
In Indium	120.	86.0	200.	0.45
Li Lithium	5.8	5.1	11.0	0.02
Mn Manganese	[26.0]	5.1	[32.0]	[0.07]
Mo Molybdenum	23.0	26.0	49.0	0.11
Ni Nickel	23.0	[26.0]	49.0	[0.11]
Pb Lead	[35.0]	26.0	[60.0]	[0.13]
Sb Antimony	46.0	43.0	89.0	0.20
Sc Scandium	58.0	51.0	110.	0.24
Se Selenium	1.2	0.86	2.0	0.005
Sn Tin	230.	260.	490.	11.0
Sr Strontium	5.8	5.1	11.0	0.02
Te Tellurium	58.0	51.0	110.	0.24
Ti Titanium	120.	86.0	200.	0.45
Tl Thallium	58.0	51.0	110.	0.24
V Vanadium	5.8	5.1	11.0	0.024
Zn Zinc	[110.]	[310.]	[420.]	[0.94]

All elements except those in boxes ☐ are below the limit of detection

Table 6.7 Metal Concentrations in Amine Contactor Outlet Stream at the Gulf-Pincher Creek Gas Plant During Test #3

Source: Gulf - Pincher Creek Contactor Outlet | Test No: 3 | Date: March 30, 1983

Sample Analyses	Micrograms Probe	Micrograms Impingers	Total Elemental Weight ug	Elemental Concentration ug/scf
Ag Silver	[2.9]	[5.4]	[8.2]	[0.018]
Al Aluminum	48.0	77.0	120.	0.28
As Arsenic	0.24	0.54	0.78	0.002
B Boron	580.	770.	1300	3.0
Be Beryllium	0.96	2.3	3.3	0.007
Cd Cadmium	0.96	[13.0]	[14.0]	[0.031]
Co Cobalt	9.6	23.0	33.0	0.07
Cr Chromium	9.6	23.0	33.0	0.07
Cu Copper	[24.0]	[77.0]	[91.0]	[0.20]
Fe Iron	[19.0]	[510.]	[530.]	[1.2]
Ga Gallium	96.0	230.	330.	0.73
Ge Germanium	96.0	230.	330.	0.73
Hg Mercury	1.4	3.1	4.5	0.010
In Indium	48.0	77.0	120.	0.28
Li Lithium	2.4	5.4	7.8	0.017
Mn Manganese	2.4	[13.0]	[15.0]	[0.035]
Mo Molybdenum	9.6	23.0	33.0	0.073
Ni Nickel	9.6	[54.0]	[63.3]	[0.14]
Pb Lead	9.6	54.0	63.0	0.14
Sb Antimony	19.0	38.0	57.0	0.13
Sc Scandium	24.0	54.0	78.0	0.17
Se Selenium	0.48	0.77	1.2	0.003
Sn Tin	48.0	77.0	120.	0.28
Sr Strontium	2.4	5.3	7.8	0.017
Te Tellurium	24.0	54.0	78.0	0.17
Ti Titanium	48.0	77.0	120.	0.28
Tl Thallium	24.0	54.0	78.0	0.17
V Vanadium	2.4	5.4	7.8	0.017
Zn Zinc	1.4	[310.]	[320.]	[0.71]

All elements except those in boxes [ ] are below the limit of detection

Table 6.8 Qualitative Assessment of Metals in Condensate Stabilizer Overhead Stream at the Gulf-Pincher Creek Gas Plant From Test #1

Source: Gulf - Pincher Creek Condensate Stabilizer Overhead | Test No: 1 | Date: April 1, 1983

Sample Analyses	Micrograms Probe	Micrograms Impingers	Total Elemental Weight ug	Elemental Concentration ug/rcf
Ag Silver		5.91		
Al Aluminum		98.5		
As Arsenic		0.591		
B Boron		1970		
Be Beryllium		3.94		
Cd Cadmium		3.94		
Co Cobalt		19.7		
Cr Chromium		19.7		
Cu Copper		531.9		
Fe Iron		827.4		
Ga Gallium		197		
Ge Germanium		197		
Hg Mercury		7.88		
In Indium		98.5		
Li Lithium		5.91		
Mn Manganese		17.73		
Mo Molybdenum		59.1		
Ni Nickel		19.7		
Pb Lead		19.7		
Sb Antimony		59.1		
Sc Scandium		59.1		
Se Selenium		9.85		
Sn Tin		98.5		
Sr Strontium		5.91		
Te Tellurium		59.1		
Ti Titanium		98.5		
Tl Thallium		59.1		
V Vanadium		3.94		
Zn Zinc		98.5		

Probe Sample Bottle Broken Data Incomplete

All elements except those in boxes ☐ are below the limit of detection

Table 6.9 Metal Concentrations in Condensate Stabilizer Overhead Stream at the Gulf-Pincher Creek Gas Plant During Test #2

Source: Gulf-Pincher Creek Condensate Stabilizer Overhead | Test No: 2 | Date: April 2, 1983

Sample Analyses	Micrograms		Total Elemental Weight ug	Elemental Concentration ug/scf
	Probe	Impingers		
Ag Silver	5.6	5.2	11.0	0.04
Al Aluminum	110.	460.	570.	1.8
As Arsenic	0.56	0.52	1.1	0.003
B Boron	2200	2000	4200	13.0
Be Beryllium	2.2	2.0	4.2	0.01
Cd Cadmium	2.2	20.0	22.0	0.07
Co Cobalt	11.0	13.0	24.0	0.08
Cr Chromium	22.0	33.0	55.0	0.18
Cu Copper	11.0	65.0	76.0	0.24
Fe Iron	11.0	3400	3400	11.0
Ga Gallium	220.	200.	420.	1.3
Ge Germanium	220.	200.	420.	1.3
Hg Mercury	1.1	1.3	2.4	0.08
In Indium	110.	130.	240.	0.08
Li Lithium	5.6	5.2	11.0	0.04
Mn Manganese	5.6	31.0	37.0	0.12
Mo Molybdenum	22.0	20.0	42.0	0.13
Ni Nickel	22.0	20.0	42.0	0.13
Pb Lead	22.0	20.0	42.0	0.13
Sb Antimony	67.0	54.0	120.	0.39
Sc Scandium	56.0	52.0	110.	0.35
Se Selenium	1.1	1.3	2.4	0.008
Sn Tin	220.	200.	420.	1.3
Sr Strontium	5.6	5.2	11.0	0.04
Te Tellurium	56.0	52.0	110.	0.35
Ti Titanium	110.	130.	240.	0.78
Tl Thallium	56.0	52.0	110.	0.35
V Vanadium	5.6	5.2	11.0	0.04
Zn Zinc	10.0	780.	790.	2.5

All elements except those in boxes ☐ are below the limit of detection

Table 6.10 Metal Concentrations in Condensate Stabilizer Overhead Stream at the Gulf-Pincher Creek Gas Plant During Test #3

Source: Gulf-Pincher Creek Condensate Stabilizer Overhead | Test No: 3 | Date: April 2, 1983

Sample Analyses	Micrograms Probe	Micrograms Impingers	Total Elemental Weight ug	Elemental Concentration ug/scf
Ag Silver	6.8	5.0	12.0	0.04
Al Aluminum	140.	4300	4400	14.3
As Arsenic	0.68	13.3	13.3	0.04
B Boron	1400	840.	2200	7.0
Be Beryllium	2.7	2.5	5.2	0.02
Cd Cadmium	80.0	280.	360.	1.2
Co Cobalt	27.0	25.0	52.0	0.17
Cr Chromium	27.0	250.	280.	0.89
Cu Copper	540.	4300	4800	15.3
Fe Iron	35000	7400	42000	140.
Ga Gallium	270.	250.	520.	1.7
Ge Germanium	270.	250.	520.	1.7
Hg Mercury	4.1	3.3	7.4	0.02
In Indium	140.	84.0	220.	0.70
Li Lithium	6.8	5.0	12.0	0.04
Mn Manganese	340.	170.	500.	1.6
Mo Molybdenum	27.0	25.0	52.0	0.17
Ni Nickel	27.0	160.	190.	0.59
Pb Lead	230.	760.	990.	3.2
Sb Antimony	54.0	42.0	96.0	0.31
Sc Scandium	68.0	50.0	120.	0.38
Se Selenium	1.4	0.84	2.2	0.007
Sn Tin	140.	84.0	220.	0.70
Sr Strontium	6.8	5.0	12.0	0.04
Te Tellurium	68.0	50.0	120.	0.38
Ti Titanium	140.	84.0	220.	0.70
Tl Thallium	68.0	50.0	120.	0.38
V Vanadium	6.8	5.0	12.0	0.04
Zn Zinc	1800	12000	13000	43.0

All elements except those in boxes ☐ are below the limit of detection

Table 6.11 Metal Concentrations in Condensate Stabilizer Overhead Stream at the Gulf-Pincher Creek Gas Plant During Test #4

Source: Gulf-Pincher Creek Condensate Stabalizer Overhead | Test No: 4 | Date: April 2, 1983

Sample Analyses	Micrograms Probe	Micrograms Impingers	Total Elemental Weight µg	Elemental Concentration µg/scf
Ag Silver	6.2	52.0	11.0	0.04
Al Aluminum	120.	87.0	210.	0.69
As Arsenic	0.62	0.52	1.1	0.004
B Boron	1200	870.	2100	6.9
Be Beryllium	2.5	1.7	4.2	0.014
Cd Cadmium	2.5	5.2	7.7	0.025
Co Cobalt	25.0	17.0	42.0	0.14
Cr Chromium	62.5	17.0	79.0	0.26
Cu Copper	210	8.7	220	0.72
Fe Iron	640	660	1300	4.3
Ga Gallium	250.	170.	420.	1.4
Ge Germanium	250.	170.	420.	1.4
Hg Mercury	3.7	3.5	7.2	0.02
In Indium	120.	87.0	210.	0.69
Li Lithium	6.2	5.2	11.0	0.04
Mn Manganese	7.4	7.8	15.3	0.050
Mo Molybdenum	25.0	17.0	42.0	0.14
Ni Nickel	25.0	17.0	42.0	0.14
Pb Lead	25.0	5.2	30.0	0.10
Sb Antimony	50.0	43.0	93.0	0.31
Sc Scandium	62.0	52.0	110.	0.38
Se Selenium	1.2	1.7	3.0	0.010
Sn Tin	120.	87.0	210.	0.69
Sr Strontium	6.2	5.2	11.0	0.04
Te Tellurium	62.0	52.0	110.	0.38
Ti Titanium	120.	87.0	210.	0.69
Tl Thallium	62.0	52.0	110.	0.38
V Vanadium	6.2	5.2	11.0	0.04
Zn Zinc	60.2	110	170	0.57

All elements except those in boxes ☐ are below the limit of detection

Table 6.12 Metal Concentrations in Dehydrator Inlet Stream at the Gulf-Pincher Creek Gas Plant During Test #1

Source: Gulf-Pincher Creek Dehydrator Inlet | Test No: 1 | Date: March 30, 1983

Sample Analyses	Micrograms		Total Elemental Weight ug	Elemental Concentration ug/rcf
	Probe	Impingers		
Ag Silver	4.6	4.8	9.4	0.02
Al Aluminum	92.0	1400	1500	3.9
As Arsenic	0.46	0.48	0.94	0.002
B Boron	1800	2000	3900	9.8
Be Beryllium	2.8	3.2	6.0	0.02
Cd Cadmium	1.8	2.4	4.3	0.01
Co Cobalt	18.0	24.0	43.0	0.11
Cr Chromium	18.0	32.0	51.0	0.13
Cu Copper	100.	24.0	130.	0.32
Fe Iron	120.	190.	300.	0.78
Ga Gallium	180.	240.	430.	1.1
Ge Germanium	180.	240.	430.	1.1
Hg Mercury	0.92	0.81	1.7	0.004
In Indium	92.0	81.0	170.	0.44
Li Lithium	4.6	4.8	9.4	0.02
Mn Manganese	4.6	12.0	19.0	0.04
Mo Molybdenum	46.0	48.0	94.0	0.24
Ni Nickel	18.0	81.0	99.0	0.25
Pb Lead	18.0	24.0	43.0	0.11
Sb Antimony	46.0	48.0	94.0	0.24
Sc Scandium	46.0	48.0	94.0	0.24
Se Selenium	0.92	0.81	1.7	0.004
Sn Tin	92.0	81.0	170.	0.44
Sr Strontium	4.6	4.8	9.4	0.24
Te Tellurium	46.0	48.0	94.0	0.24
Ti Titanium	92.0	81.0	170.	0.44
Tl Thallium	46.0	48.0	94.0	0.24
V Vanadium	1.8	2.4	4.3	0.01
Zn Zinc	79.0	520.	600.	1.5

All elements except those in boxes ☐ are below the limit of detection

Table 6.13 Qualitative Assessment of Metals in Dehydrator Inlet Stream at the Gulf-Pincher Creek Gas Plant From Test #2

Source: Gulf-Pincher Creek Dehydrator Inlet | Test No: 2 | Date: March 31, 1983

Sample Analyses	Micrograms Probe	Micrograms Impingers	Total Elemental Weight ug	Elemental Concentration ug/ref
Ag Silver	Sample	5.6	5.6	0.02
Al Aluminum	Bottle	241	241	0.67
As Arsenic	Broken	0.6	0.6	0.002
B Boron		2420	2420	6.71
Be Beryllium		2.4	2.4	0.01
Cd Cadmium		4.0	4.0	0.01
Co Cobalt		8.05	8.1	0.02
Cr Chromium		40.3	40.3	0.11
Cu Copper		483	483	1.34
Fe Iron		1210	1210	3.35
Ga Gallium		242	242	0.67
Ge Germanium		242	242	0.67
Hg Mercury		0.8	0.8	0.002
In Indium		80.5	80.5	0.22
Li Lithium		5.6	5.6	0.02
Mn Manganese		13.7	13.7	0.04
Mo Molybdenum		24.2	24.2	0.07
Ni Nickel		120.8	120.8	0.34
Pb Lead		24.2	24.2	0.07
Sb Antimony		40.3	40.3	0.11
Sc Scandium		56.4	56.4	0.16
Se Selenium		0.8	0.8	0.002
Sn Tin		242	242	0.67
Sr Strontium		5.6	5.6	0.02
Te Tellurium		56.4	56.4	0.16
Ti Titanium		80.5	80.5	0.22
Tl Thallium		56.4	56.4	0.16
V Vanadium		5.6	5.6	0.02
Zn Zinc		258	258	0.72

All elements except those in boxes ☐ are below the limit of detection

Table 6.14 Metal Concentrations in Dehydrator Inlet Stream at the Gulf-Pincher Creek Gas Plant During Test #3

Source: Gulf-Pincher Creek Dehydrator Inlet | Test No: 3 | Date: March 31, 1983

Sample Analyses	Micrograms Probe	Micrograms Impingers	Total Elemental Weight ug	Elemental Concentration ug/rcf
Ag Silver	4.6	[7.2]	[12.3]	[0.031]
Al Aluminum	92.0	[240]	[330]	[0.84]
As Arsenic	0.46	0.56	1.0	0.003
B Boron	920.	800.	1700	4.4
Be Beryllium	1.84	2.4	4.2	0.01
Cd Cadmium	1.8	[3.2]	[5.0]	[0.01]
Co Cobalt	18.4	24.0	42.0	0.11
Cr Chromium	18.0	24.0	42.0	0.11
Cu Copper	[9.2]	[32.1]	[41.3]	[0.10]
Fe Iron	[18.0]	[180.]	[200.]	[0.51]
Ga Gallium	180.	240.	420.	1.1
Ge Germanium	180.	240.	420.	1.1
Hg Mercury	2.8	3.2	5.9	0.02
In Indium	92.0	80.0	170.	0.44
Li Lithium	4.6	5.6	10.0	0.03
Mn Manganese	4.6	[7.2]	[12.3]	[0.03]
Mo Molybdenum	18.0	24.0	42.0	0.11
Ni Nickel	18.0	[64.3]	[82.3]	[0.21]
Pb Lead	18.0	24.0	42.0	0.11
Sb Antimony	37.0	40.0	77.0	0.20
Sc Scandium	46.0	56.0	100.	0.26
Se Selenium	0.92	0.80	1.7	0.004
Sn Tin	92.0	80.0	170.	0.44
Sr Strontium	4.6	5.6	10.0	0.03
Te Tellurium	46.0	56.0	100.	0.26
Ti Titanium	92.0	80.0	170.	0.44
Tl Thallium	46.0	56.0	100.	0.26
V Vanadium	4.6	5.6	10.0	0.03
Zn Zinc	[26.3]	[260.]	[290.]	[0.73]

All elements except those in boxes ☐ are below the limit of detection

Table 6.15 Metal Concentrations in Sales Gas Stream at the Gulf-Pincher Creek Gas Plant During Test #1

Source: Gulf - Pincher Creek Sales Gas Test No: 1 Date: March 29, 1983

Sample Analyses	Micrograms Probe	Micrograms Impingers	Total Elemental Weight ug	Elemental Concentration ug/rcf
Ag Silver	4.5	5.2	9.7	0.029
Al Aluminum	90.0	260.	350.	1.1
As Arsenic	0.45	0.52	0.97	0.003
B Boron	1800	2200	4000	12.0
Be Beryllium	2.7	3.5	6.2	0.019
Cd Cadmium	61.0	4.4	66.0	0.20
Co Cobalt	18.0	26.0	44.0	0.13
Cr Chromium	18.0	44.0	62.0	0.18
Cu Copper	18.0	70.0	88.0	0.26
Fe Iron	1200	510.	1700	5.0
Ga Gallium	180.	260.	440.	1.3
Ge Germanium	180.	260.	440.	1.3
Hg Mercury	0.90	0.87	1.8	0.005
In Indium	90.0	87.0	180.	0.53
Li Lithium	4.5	5.2	9.7	0.029
Mn Manganese	9.0	17.0	26.0	0.077
Mo Molybdenum	45.0	96.0	140.	0.42
Ni Nickel	18.0	44.0	62.0	0.18
Pb Lead	18.0	26.0	44.0	0.13
Sb Antimony	45.0	52.0	97.0	0.29
Sc Scandium	45.0	52.0	97.0	0.29
Se Selenium	0.90	0.87	1.8	0.005
Sn Tin	90.0	87.0	180.	0.53
Sr Strontium	4.5	5.2	9.7	0.029
Te Tellurium	45.0	52.0	97.0	0.29
Ti Titanium	90.0	87.0	180.	0.53
Tl Thallium	45.0	52.0	97.0	0.29
V Vanadium	1.8	3.5	5.3	0.016
Zn Zinc	43.0	2100	2100	6.4

All elements except those in boxes ☐ are below the limit of detection

Table 6.16 Metal Concentrations in Sales Gas Stream at the Gulf-Pincher Creek Gas Plant During Test #2

Source: Gulf - Pincher Creek Sales Gas | Test No: 2 | Date: March 29, 1983

Sample Analyses	Micrograms Probe	Micrograms Impingers	Total Elemental Weight ug	Elemental Concentration ug/rcf
Ag Silver	4.2	5.2	9.4	0.028
Al Aluminum	84.0	22000	22000	66.3
As Arsenic	0.42	25.0	25.0	0.074
B Boron	1700	2200	3900	12.0
Be Beryllium	1.7	2.2	3.9	0.012
Cd Cadmium	1.7	7.5	9.1	0.027
Co Cobalt	8.4	7.5	16.0	0.047
Cr Chromium	17.0	150.	170.	0.49
Cu Copper	17.0	7.5	24.5	0.071
Fe Iron	59.0	670.	730.	2.1
Ga Gallium	170.	220.	390.	1.2
Ge Germanium	170.	220.	390.	1.2
Hg Mercury	0.84	0.75	1.6	0.005
In Indium	84.0	75.0	160.	0.47
Li Lithium	4.2	5.2	9.4	0.028
Mn Manganese	4.2	22.0	26.0	0.076
Mo Molybdenum	17.0	22.0	39.0	0.12
Ni Nickel	17.0	22.0	39.0	0.12
Pb Lead	17.0	22.0	39.0	0.12
Sb Antimony	34.0	45.0	78.0	0.23
Sc Scandium	42.0	52.0	94.0	0.28
Se Selenium	0.84	0.75	1.6	0.005
Sn Tin	170.	220.	390.	1.2
Sr Strontium	4.2	5.2	9.4	0.028
Te Tellurium	42.0	52.0	94.0	0.28
Ti Titanium	84.0	75.0	160.	0.47
Tl Thallium	42.0	52.0	94.0	0.28
V Vanadium	4.2	5.2	9.4	0.028
Zn Zinc	30.0	1400	1400	4.3

All elements except those in boxes ☐ are below the limit of detection

Table 6.17 Metal Concentrations in Sales Gas Stream at the Gulf-Pincher Creek Gas Plant During Test #3

Source: Gulf - Pincher Creek Sales Gas Test No: 3 Date: March 30, 1983

Sample Analyses	Micrograms		Total Elemental Weight ug	Elemental Concentration ug/Rcf
	Probe	Impingers		
Ag Silver	3.0	[5.4]	[8.4]	[0.022]
Al Aluminum	60.0	77.0	140.	0.35
As Arsenic	0.30	0.54	0.84	0.002
B Boron	600.	770.	1400	3.5
Be Beryllium	1.2	2.3	3.5	0.009
Cd Cadmium	1.2	[4.1]	[5.3]	[0.014]
Co Cobalt	12.0	23.0	35.0	0.09
Cr Chromium	12.0	23.0	35.0	0.09
Cu Copper	[18.0]	[23.0]	[41.0]	[0.11]
Fe Iron	[24.0]	[150.]	[180.]	[0.46]
Ga Gallium	120.	230.	350.	0.91
Ge Germanium	120.	230.	350.	0.91
Hg Mercury	1.8	3.1	4.9	0.013
In Indium	60.0	77.0	140.	0.35
Li Lithium	3.0	5.4	8.4	0.022
Mn Manganese	3.0	5.4	8.4	0.022
Mo Molybdenum	12.0	23.0	35.0	0.090
Ni Nickel	12.0	[54.0]	[66.0]	[0.170]
Pb Lead	12.0	23.0	35.0	0.090
Sb Antimony	24.0	38.0	62.0	0.16
Sc Scandium	30.0	54.0	84.0	0.22
Se Selenium	0.60	0.77	1.40	0.004
Sn Tin	60.0	77.0	140.	0.35
Sr Strontium	3.0	5.4	8.4	0.022
Te Tellurium	30.0	54.0	84.0	0.22
Ti Titanium	60.0	77.0	140.	0.35
Tl Thallium	30.0	54.0	84.0	0.22
V Vanadium	3.0	5.4	8.4	0.022
Zn Zinc	1.8	[680.]	[690.]	[1.8]

All elements except those in boxes [ ] are below the limit of detection

Table 6.18 Metal Concentrations in Acid Gas Stream at the Gulf-Pincher Creek Gas Plant During Test #1

Source: Gulf-Pincher Creek Acid Gas | Test No: 1 | Date: April 1, 1983

Sample Analyses	Micrograms		Total Elemental Weight ug	Elemental Concentration ug/rcf
	Probe	Impingers		
Ag Silver	7.2	5.3	13.0	0.15
Al Aluminum	140.	9500	9700	110
As Arsenic	0.72	21.3	22.0	0.26
B Boron	2900	2000	4900	57.0
Be Beryllium	4.3	23.0	27.3	0.32
Cd Cadmium	4.3	120	120	1.4
Co Cobalt	29.0	27.0	55.0	0.65
Cr Chromium	29.0	1200	1230	15.0
Cu Copper	58.0	370	430	5.0
Fe Iron	4000	61000	65000	760
Ga Gallium	290	270	550	6.5
Ge Germanium	290	270	550	6.5
Hg Mercury	1.4	1.3	2.8	0.03
In Indium	140.	110.	250	2.9
Li Lithium	7.2	15.0	22.3	0.26
Mn Manganese	29.0	8100	8100	95.3
Mo Molybdenum	7.2	66.0	73.0	0.86
Ni Nickel	29.0	53.3	82.3	0.96
Pb Lead	86.0	250	140	4.0
Sb Antimony	72.0	53.0	130.	1.5
Sc Scandium	72.0	53.0	130.	1.5
Se Selenium	1.4	1.1	2.5	0.03
Sn Tin	140.	110.	250.	2.9
Sr Strontium	7.2	130	140	1.6
Te Tellurium	72.0	53.0	130.	1.5
Ti Titanium	140.	110.	250.	2.9
Tl Thallium	72.0	53.0	130.	1.5
V Vanadium	2.9	6.6	9.5	0.11
Zn Zinc	120	990	1100	13.0

All elements except those in boxes ☐ are below the limit of detection

Table 6.19 Metal Concentrations in Acid Gas Stream at the Gulf-Pincher Creek Gas Plant During Test #2

Source: Gulf-Pincher Creek Acid Gas | Test No: 2 | Date: April 1, 1983

Sample Analyses	Micrograms		Total Elemental Weight ug	Elemental Concentration ug/ref
	Probe	Impingers		
Ag Silver	5.9	4.9	11.0	0.23
Al Aluminum	120.	240.	360.	7.8
As Arsenic	0.59	0.49	1.1	0.02
B Boron	2400	2400	4800	100.
Be Beryllium	2.4	2.4	4.8	0.10
Cd Cadmium	0.71	15.3	15.3	0.33
Co Cobalt	12.0	11.0	23.0	0.49
Cr Chromium	24.0	500.	520.	11.3
Cu Copper	12.0	11.0	23.3	0.49
Fe Iron	1100.	19000	21000	440.
Ga Gallium	240.	240.	480.	10.0
Ge Germanium	240.	240.	480.	10.0
Hg Mercury	1.2	1.1	2.3	0.05
In Indium	120.	110.	230.	4.9
Li Lithium	5.9	4.9	11.0	0.23
Mn Manganese	9.4	2400	2400	53.3
Mo Molybdenum	24.0	24.0	48.0	1.0
Ni Nickel	24.0	24.0	48.0	1.0
Pb Lead	24.0	36.0	60.3	1.3
Sb Antimony	47.0	36.0	84.0	1.8
Sc Scandium	59.0	49.0	110.	2.3
Se Selenium	1.2	1.1	2.3	0.05
Sn Tin	240.	240.	480.	10.0
Sr Strontium	5.9	17.3	23.3	0.49
Te Tellurium	59.0	49.0	110.	2.3
Ti Titanium	120.	110.	230.	4.9
Tl Thallium	59.0	49.0	110.	2.3
V Vanadium	5.9	4.9	11.0	0.23
Zn Zinc	71.0	240.	310.	6.8

All elements except those in boxes ☐ are below the limit of detection

Table 6.20 Metal Concentrations in Acid Gas Stream at the Gulf-Pincher Creek Gas Plant During Test #3

Source: Gulf-Pincher Creek Acid Gas | Test No: 3 | Date: April 2, 1983

Sample Analyses	Micrograms		Total Elemental Weight ug	Elemental Concentration ug/rcf
	Probe	Impingers		
Ag Silver	[9.0]	5.2	[14.0]	[0.35]
Al Aluminum	130.	[11000]	[11000]	[280.]
As Arsenic	[0.65]	[9.5]	[10.0]	[0.25]
B Boron	1300	870.	2200	53.0
Be Beryllium	2.6	1.7	4.3	0.11
Cd Cadmium	[3.9]	[39.0]	[43.0]	[1.1]
Co Cobalt	26.0	17.0	43.0	1.1
Cr Chromium	26.0	[290.]	[320.]	[7.9]
Cu Copper	[13.0]	[52.0]	[65.0]	[1.6]
Fe Iron	[840.]	[57000]	[58000]	[1400]
Ga Gallium	260.	170.	430.	11.0
Ge Germanium	260.	170.	430.	11.0
Hg Mercury	3.9	3.5	7.3	0.18
In Indium	130.	87.0	220.	5.3
Li Lithium	6.5	5.2	12.0	0.29
Mn Manganese	6.5	[2100]	[2100]	[51.0]
Mo Molybdenum	26.0	17.0	43.0	1.1
Ni Nickel	26.0	[17.0]	[43.0]	[1.1]
Pb Lead	26.0	[35.0]	[60.0]	[1.5]
Sb Antimony	52.0	43.0	95.0	2.3
Sc Scandium	65.0	52.0	120.	2.9
Se Selenium	1.3	1.7	3.0	0.08
Sn Tin	130.	87.0	220.	5.3
Sr Strontium	6.5	5.2	12.0	0.29
Te Tellurium	65.0	52.0	120.	2.9
Ti Titanium	130.	87.0	220.	5.3
Tl Thallium	65.0	52.0	120.	2.9
V Vanadium	6.5	5.2	12.0	0.29
Zn Zinc	[440.]	[6100]	[6600]	[160.]

All elements except those in boxes ☐ are below the limit of detection

Figure 2.1. Figure 6.1 provides a comparison of the concentrations of metals whose presence was detected in the streams entering or leaving the various units of the plant.

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Tables 6.21 to 6.38 provide the results of the sampling program at the Waterton Gas Plant. The data are presented according to the sampling site identification scheme of Figure 2.2. A comparison of the concentrations of metals whose presence was detected in the different process streams is provided in Figure 6.2.

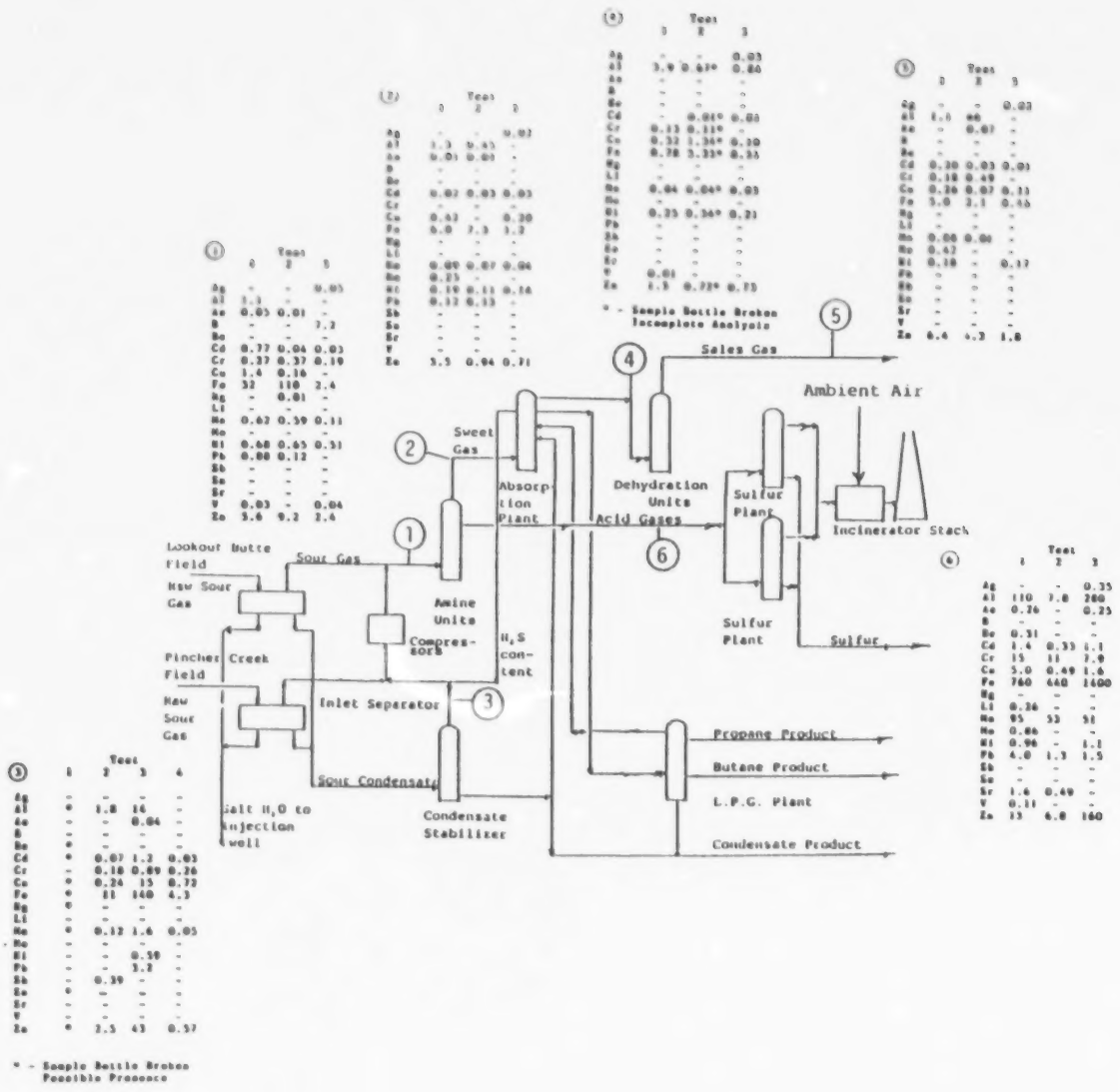

Figure 6.1 Summary of Metal Concentrations in Various Process Streams at the Gulf Oil Canada Limited Pincher Creek Gas Plant (µg/rcf)

Table 6.21 Metal Concentrations in Raw Gas Stream Entering the Lean Oil Absorption Units at the Shell-Waterton Gas Plant During Test #1

Source: Shell-Waterton Raw Gas Inlet | Test No: 1 | Date: April 6, 1983

Sample Analyses	Micrograms		Total Elemental Weight ug	Elemental Concentration ug/scf
	Probe	Impingers		
Ag Silver	5.8	5.4	11.0	0.03
Al Aluminum	120.	78.0	190.	0.53
As Arsenic	0.58	0.54	1.1	0.003
B Boron	2300	2200	4500	12.0
Be Beryllium	2.3	3.1	5.4	0.01
Cd Cadmium	2.3	2.3	4.6	0.01
Co Cobalt	23.0	23.0	46.0	0.13
Cr Chromium	23.0	47.0	70.0	0.19
Cu Copper	12.0	7.8	19.0	0.05
Fe Iron	310.	1100	1400	3.8
Ga Gallium	230.	230.	460.	1.3
Ge Germanium	230.	230.	460.	1.3
Hg Mercury	1.2	0.78	1.9	0.005
In Indium	120.	78.0	190.	0.53
Li Lithium	5.8	5.4	11.0	0.03
Mn Manganese	8.1	31.0	39.0	0.11
Mo Molybdenum	58.0	54.0	110.	0.31
Ni Nickel	23.0	23.0	46.0	0.13
Pb Lead	23.0	31.0	54.0	0.15
Sb Antimony	58.0	54.0	110.	0.31
Sc Scandium	58.0	54.0	110.	0.31
Se Selenium	1.2	0.78	1.9	0.005
Sn Tin	120.	78.0	190.	0.53
Sr Strontium	5.8	5.4	11.0	0.03
Te Tellurium	58.0	54.0	110.	0.31
Ti Titanium	120.	78.0	190.	0.53
Tl Thallium	58.0	54.0	110.	0.31
V Vanadium	2.3	2.3	4.6	0.01
Zn Zinc	25.0	100.	130.	0.35

All elements except those in boxes ☐ are below the limit of detection

Table 6.22 Metal Concentrations in Raw Gas Stream Entering the Lean Oil Absorption Units at the Shell-Waterton Gas Plant During Test #2

Source: Shell-Waterton Raw Gas Inlet | Test No: 2 | Date: April 6, 1983

Sample Analyses	Micrograms		Total Elemental Weight ug	Elemental Concentration ug/rcf
	Probe	Impingers		
Ag Silver	5.9	5.2	11.0	0.04
Al Aluminum	120.	130.	250.	0.82
As Arsenic	0.59	0.46	1.0	0.003
B Boron	2400	2000	4300	14.0
Be Beryllium	2.4	2.0	4.3	0.01
Cd Cadmium	2.4	2.0	4.3	0.01
Co Cobalt	12.0	13.0	25.0	0.08
Cr Chromium	24.0	20.0	43.0	0.14
Cu Copper	12.0	13.0	25.0	0.08
Fe Iron	190.	520.	710.	2.4
Ga Gallium	240.	200.	430.	1.4
Ge Germanium	240.	200.	430.	1.4
Hg Mercury	1.2	1.3	2.5	0.008
In Indium	120.	130.	250.	0.82
Li Lithium	5.9	5.2	11.0	0.04
Mn Manganese	5.9	6.5	12.0	0.04
Mo Molybdenum	24.0	20.0	43.0	0.14
Ni Nickel	24.0	20.0	43.0	0.14
Pb Lead	24.0	20.0	43.0	0.14
Sb Antimony	47.0	46.0	93.0	0.31
Sc Scandium	59.0	52.0	110.	0.37
Se Selenium	1.2	1.3	2.5	0.008
Sn Tin	240.	200.	430.	1.4
Sr Strontium	6.0	5.2	11.0	0.04
Te Tellurium	59.0	52.0	110.	0.37
Ti Titanium	120.	130.	250.	0.82
Tl Thallium	59.0	52.0	110.	0.37
V Vanadium	5.9	5.2	11.0	0.04
Zn Zinc	41.0	140.	180.	0.61

All elements except those in boxes ☐ are below the limit of detection

Table 6.23 Metal Concentrations in Raw Gas Stream Entering the Lean Oil Absorption Units at the Shell-Waterton Gas Plant During Test #3

Source: Shell-Watercon Raw Gas Inlet | Test No: 3 | Date: April 7, 1983

Sample Analyses	Micrograms Probe	Micrograms Impingers	Total Elemental Weight ug	Elemental Concentration ug/rcf
Ag Silver	8.9	6.7	16.3	0.09
Al Aluminum	130.	84.3	210	0.73
As Arsenic	0.64	4.2	4.8	0.02
B Boron	1300	840.	2100	7.2
Be Beryllium	2.5	2.5	5.1	0.02
Cd Cadmium	2.5	17.0	19.0	0.07
Co Cobalt	25.0	25.0	51.0	0.17
Cr Chromium	25.0	170.	190.	0.66
Cu Copper	51.0	8.4	59.3	0.20
Fe Iron	3600	5700	6600	22.0
Ga Gallium	250.	250.	510.	1.7
Ge Germanium	250.	250.	510.	1.7
Hg Mercury	6.4	42.0	48.0	0.16
In Indium	130.	51.	180.	0.60
Li Lithium	6.4	5.1	11.0	0.04
Mn Manganese	6.4	5.1	11.0	0.04
Mo Molybdenum	25.0	25.0	51.0	0.17
Ni Nickel	25.0	25.0	51.0	0.17
Pb Lead	25.0	25.0	51.0	0.17
Sb Antimony	51.0	42.0	93.0	0.32
Sc Scandium	64.0	51.0	110.	0.39
Se Selenium	1.3	8.4	9.7	0.03
Sn Tin	130.	84.0	210.	0.72
Sr Strontium	6.4	5.1	11.0	0.04
Te Tellurium	64.0	420.	480.	1.6
Ti Titanium	130.	84.0	210.	0.72
Tl Thallium	64.0	420.	480.	1.6
V Vanadium	6.4	42.0	48.0	0.16
Zn Zinc	34.0	100	140	0.48

All elements except those in boxes ☐ are below the limit of detection

Table 6.24 Metal Concentrations in Lean Oil Absorption Unit Overhead Stream at the Shell-Waterton Gas Plant During Test #1

Source: Shell-Waterton Absorber Overheads | Test No 1 | Date: April 4, 1983

Sample Analyses	Micrograms Probe	Micrograms Impingers	Total Elemental Weight ug	Elemental Concentration ug/rcf
Ag Silver	5.0	[15.0]	[20.0]	[0.06]
Al Aluminum	100.	[300.]	[400.]	[1.1]
As Arsenic	0.5	[1.2]	[1.7]	[0.005]
B Boron	2000	2100	4100	13.0
Be Beryllium	3.0	3.0	6.0	0.02
Cd Cadmium	2.0	16.0	18.0	0.06
Co Cobalt	20.0	24.0	44.0	0.14
Cr Chromium	20.0	[59.0]	[79.0]	0.25
Cu Copper	10.0	[35.0]	[45.0]	0.14
Fe Iron	[2500]	[89000]	[91000]	[290]
Ga Gallium	200.	240.	440.	1.4
Ge Germanium	200.	240.	440.	1.4
Hg Mercury	1.0	1.2	2.2	0.007
In Indium	100.	120.	220.	0.69
Li Lithium	5.0	53.0	58.0	0.18
Mn Manganese	[68.0]	[1700]	[1900]	[5.6]
Mo Molybdenum	50.0	53.0	100.	0.33
Ni Nickel	20.0	[30.0]	[50.0]	[0.16]
Pb Lead	[20.0]	[110.]	[130.]	[0.40]
Sb Antimony	50.0	53.0	100.	0.33
Sc Scandium	50.0	53.0	100.	0.33
Se Selenium	1.0	1.2	2.2	0.007
Sn Tin	100.	120.	220.	0.69
Sr Strontium	5.0	5.3	10.0	0.03
Te Tellurium	50.0	53.0	100.	0.33
Ti Titanium	100.	120.	220.	0.69
Tl Thallium	50.0	53.0	100.	0.33
V Vanadium	2.0	2.4	4.4	0.01
Zn Zinc	[330.]	[1000]	[1300]	[4.2]

All elements except those in boxes ☐ are below the limit of detection

Table 6.25 Metal Concentrations in Lean Oil Absorption Unit Overhead Stream at the Shell-Waterton Gas Plant During Test #2

Source: Shell-Waterton Absorber Overheads Test No. 2 Date April 5, 1983

Sample Analyses	Micrograms		Total Elemental Weight ug	Elemental Concentration ug/m³
	Probe	Impingers		
Ag Silver	5.1	5.2	10.3	0.04
Al Aluminum	100.	74.0	180.	0.63
As Arsenic	0.51	0.52	1.0	0.004
B Boron	2000	2200	4300	15.0
Be Beryllium	20.0	2.2	4.3	0.02
Cd Cadmium	2.0	2.2	4.3	0.02
Co Cobalt	10.0	7.4	18.0	0.06
Cr Chromium	20.0	32.3	52.3	0.19
Cu Copper	10.0	7.4	18.0	0.06
Fe Iron	920.	22000	23000	83.3
Ga Gallium	200.	220.	430.	1.5
Ge Germanium	200.	220.	430.	1.5
Hg Mercury	1.0	0.74	1.8	0.006
In Indium	100.	74.0	175.	0.63
Li Lithium	51.0	52.0	10.0	0.04
Mn Manganese	49.0	380.	420.	1.5
Mo Molybdenum	20.0	22.0	43.0	0.15
Ni Nickel	20.0	22.0	43.0	0.15
Pb Lead	61.3	120.	180.	0.64
Sb Antimony	41.0	44.0	85.0	0.31
Sc Scandium	51.0	52.0	100.	0.37
Se Selenium	1.0	0.74	1.8	0.006
Sn Tin	200.	220.	430.	1.5
Sr Strontium	5.1	5.2	10.3	0.04
Te Tellurium	51.0	52.0	100.	0.37
Ti Titanium	100.	74.0	180.	0.63
Tl Thallium	51.0	52.0	100.	0.37
V Vanadium	5.1	5.2	10.3	0.04
Zn Zinc	51.0	520.	570.	2.1

All elements except those in boxes ☐ are below the limit of detection

Table 6.26 Qualitative Assessment of Metals in Lean Oil Absorption Unit Overhead Stream at the Shell-Waterton Gas Plant During Test #3

Source: Shell-Waterton Absorber Overheads | Test No: 3 | Date: April 5, 1983

Sample Analyses	Micrograms Probe	Micrograms Impingers	Total Elemental Weight ug	Elemental Concentration ug/rcf
Ag Silver	Sample	5.0	5.0	0.02
Al Aluminum	Bottle	1880	1880	5.76
As Arsenic	Broken	0.7	0.7	0.002
B Boron		992	992	3.03
Be Beryllium		2.0	2.0	0.01
Cd Cadmium		3.2	3.2	0.01
Co Cobalt		19.8	19.8	0.06
Cr Chromium		19.8	19.8	0.06
Cu Copper		9.9	9.9	0.03
Fe Iron		714	714	2.18
Ga Gallium		198	198	0.61
Ge Germanium		198	198	0.61
Hg Mercury		3.0	3.0	0.01
In Indium		99.2	99.2	0.30
Li Lithium		0	5.0	0.02
Mn Manganese		17.3	17.3	0.05
Mo Molybdenum		19.8	19.8	0.06
Ni Nickel		19.8	19.8	0.06
Pb Lead		69.4	69.4	0.21
Sb Antimony		39.7	39.7	0.12
Sc Scandium		49.6	49.6	0.2
Se Selenium		1.0	1.0	0.003
Sn Tin		99.2	99.2	0.30
Sr Strontium		5.0	5.0	0.02
Te Tellurium		49.6	49.6	0.2
Ti Titanium		99.2	99.2	0.30
Tl Thallium		49.6	49.6	0.2
V Vanadium		4.96	4.96	0.02
Zn Zinc		109	109	0.33

All elements except those in boxes ☐ are below the limit of detection

Table 6.27 Metal Concentrations in Dehydrator Inlet Stream at the Shell-Waterton Gas Plant During Test #1

Source: Shell-Waterton Dehydrator Inlet | Test No 1 | Date April 3, 1983

Sample Analyses	Micrograms Probe	Micrograms Impingers	Total Elemental Weight ug	Elemental Concentration ug/rcf
Ag Silver	5.0	5.5	11.0	0.03
Al Aluminum	100.	79.0	180.	0.54
As Arsenic	0.5	5.6	6.1	0.02
B Boron	2000	2100	4100	12.0
Be Beryllium	3.0	3.2	6.2	0.02
Cd Cadmium	24.0	160.	180.	0.55
Co Cobalt	20.0	24.0	44.0	0.13
Cr Chromium	20.0	24.0	44.0	0.13
Cu Copper	150.	620.	770	2.3
Fe Iron	5100	36000	41000	120.
Ga Gallium	200.	240.	440.	1.3
Ge Germanium	200.	240.	440.	1.3
Hg Mercury	1.0	0.79	1.8	0.005
In Indium	100.	79.0	180.	0.54
Li Lithium	5.0	5.5	11.0	0.03
Mn Manganese	63.0	530.	590.	1.8
Mo Molybdenum	50.	55.0	110.	0.32
Ni Nickel	20.0	79.0	99.0	0.30
Pb Lead	20.0	79.0	99.0	0.30
Sb Antimony	50.0	55.0	110.	0.32
Sc Scandium	50.0	55.0	110.	0.32
Se Selenium	1.0	0.79	1.8	0.005
Sn Tin	100.	79.0	180.	0.54
Sr Strontium	5.0	5.5	11.0	0.03
Te Tellurium	50.0	55.0	110.	0.32
Ti Titanium	100.	79.0	180.	0.54
Tl Thallium	50.0	55.0	110.	0.32
V Vanadium	2.0	2.4	4.4	0.01
Zn Zinc	130.	1000	1200	3.5

All elements except those in boxes ☐ are below the limit of detection

Table 6.28 Metal Concentrations in Dehydrator Inlet Stream at the Shell-Waterton Gas Plant During Test #2

Source: Shell-Waterton Dehydrator Inlet | Test No 2 | Date April 3, 1983

Sample Analyses	Micrograms Probe	Micrograms Impingers	Total Elemental Weight ug	Elemental Concentration ug/rcf
Ag Silver	4.6	5.2	9.8	0.03
Al Aluminum	92.0	130	220	0.60
As Arsenic	0.46	0.52	0.98	0.003
B Boron	1800	2000	3800	10.0
Be Beryllium	1.8	2.0	3.8	0.010
Cd Cadmium	2.8	15.0	18.0	0.05
Co Cobalt	9.2	13.0	22.0	0.060
Cr Chromium	18.0	33.0	51.0	0.14
Cu Copper	9.2	13.0	22.0	0.06
Fe Iron	120	910	1000	2.8
Ga Gallium	180.	200.	380.	1.0
Ge Germanium	180.	200.	380.	1.0
Hg Mercury	0.92	1.3	2.2	0.006
In Indium	92.0	130.	220.	0.60
Li Lithium	4.6	5.8	10.0	0.03
Mn Manganese	4.6	12.0	16.0	0.04
Mo Molybdenum	18.0	20.0	38.0	0.10
Ni Nickel	18.0	20.0	38.0	0.10
Pb Lead	18.0	20.0	38.0	0.10
Sb Antimony	83.0	98.0	180	0.49
Sc Scandium	46.0	52.0	98.0	0.26
Se Selenium	0.92	1.3	2.2	0.006
Sn Tin	180.	200.	380.	1.0
Sr Strontium	4.6	5.2	9.8	0.03
Te Tellurium	46.0	52.0	98.0	0.26
Ti Titanium	92.0	130.	220.	0.60
Tl Thallium	46.0	52.0	98.0	0.26
V Vanadium	4.6	5.2	9.8	0.03
Zn Zinc	40.0	120	160	0.42

All elements except those in boxes ☐ are below the limit of detection

Table 6.29 Metal Concentrations in Dehydrator Inlet Stream at the Shell-Waterton Gas Plant During Test #3

Source: Shell-Waterton Dehydrator Inlet | Test No: 3 | Date: April 4, 1983

Sample Analyses	Micrograms		Total Elemental Weight ug	Elemental Concentration ug/rcf
	Probe	Impingers		
Ag Silver	5.7	5.5	11.0	0.039
Al Aluminum	110.	140.	250.	0.88
As Arsenic	0.57	0.62	1.2	0.004
B Boron	1100	1400	2500	8.8
Be Beryllium	2.3	2.1	4.4	0.015
Cd Cadmium	3.4	19.0	23.0	0.079
Co Cobalt	23.0	21.0	44.0	0.15
Cr Chromium	23.0	21.0	44.0	0.15
Cu Copper	23.0	69.0	92.0	0.32
Fe Iron	150.	1000.	1200.	4.1
Ga Gallium	230.	210.	440.	1.5
Ge Germanium	230.	210.	440.	1.5
Hg Mercury	3.4	3.5	6.9	0.024
In Indium	110.	140.	250.	0.88
Li Lithium	5.7	5.5	11.0	0.039
Mn Manganese	5.7	19.0	25.0	0.087
Mo Molybdenum	23.0	21.0	44.0	0.15
Ni Nickel	23.0	21.0	44.0	0.15
Pb Lead	23.0	21.0	44.0	0.15
Sb Antimony	46.0	42.0	87.0	0.30
Sc Scandium	57.0	55.0	110.	0.39
Se Selenium	1.1	1.4	2.5	0.009
Sn Tin	110.	140.	250.	0.88
Sr Strontium	5.7	5.5	11.0	0.039
Te Tellurium	57.0	55.0	110.	0.39
Ti Titanium	110.	140.	250.	0.88
Tl Thallium	57.0	55.0	110.	0.39
V Vanadium	5.7	1.4	7.1	0.025
Zn Zinc	19.0	180.	200.	0.69

All elements except those in boxes ☐ are below the limit of detection

Table 6.30 Metal Concentrations in Sales Gas Stream at the Shell-Waterton Gas Plant During Test #1

Source: Shell-Waterton Sales Gas | Test No: 1 | Date: April 3, 1983

Sample Analyses	Micrograms Probe	Micrograms Impingers	Total Elemental Weight ug	Elemental Concentration ug/scf
Ag Silver	5.1	5.4	11.0	0.029
Al Aluminum	100.	78.0	180.	0.50
As Arsenic	0.50	0.54	1.1	0.003
B Boron	2000	2200	4300	12.0
Be Beryllium	3.1	3.1	6.2	0.02
Cd Cadmium	2.0	2.3	4.4	0.01
Co Cobalt	20.0	23.0	44.0	0.12
Cr Chromium	20.0	23.0	44.0	0.12
Cu Copper	10.0	7.8	18.0	0.05
Fe Iron	61.0	340.	400.	1.1
Ga Gallium	200.	230.	440.	1.2
Ge Germanium	200.	230.	440.	1.2
Hg Mercury	1.0	0.78	1.8	0.005
In Indium	100.	78.0	180.	0.50
Li Lithium	5.1	5.4	11.0	0.03
Mn Manganese	5.1	7.8	13.0	0.04
Mo Molybdenum	51.0	54.0	110.	0.29
Ni Nickel	20.0	23.0	44.0	0.12
Pb Lead	20.0	23.0	44.0	0.12
Sb Antimony	51.0	54.0	110.	0.29
Sc Scandium	51.0	54.0	110.	0.29
Se Selenium	1.0	0.78	1.8	0.005
Sn Tin	100.	78.0	180.	0.50
Sr Strontium	5.1	5.4	11.0	0.03
Te Tellurium	51.0	54.0	110.	0.29
Ti Titanium	100.	78.0	180.	0.50
Tl Thallium	51.0	54.0	110.	0.29
V Vanadium	2.0	2.3	4.4	0.01
Zn Zinc	11.0	65.1	76.1	0.21

All elements except those in boxes ☐ are below the limit of detection

Table 6.31 Metal Concentrations in Sales Gas Stream at the Shell-Waterton Gas Plant During Test #2

Source: Shell-Waterton Sales Gas | Test No: 2 | Date: April 3, 1983

Sample Analyses	Micrograms Probe	Micrograms Impingers	Total Elemental Weight ug	Elemental Concentration ug/rcf
Ag Silver	5.6	5.0	11.0	0.03
Al Aluminum	110.	71.0	180.	0.51
As Arsenic	0.56	0.50	1.1	0.003
B Boron	2200	2100	4400	12.0
Be Beryllium	2.2	2.1	4.4	0.01
Cd Cadmium	2.2	[2.8]	[5.1]	[0.01]
Co Cobalt	11.0	7.1	18.0	0.05
Cr Chromium	22.0	[31.0]	[54.0]	[0.15]
Cu Copper	11.0	7.1	18.0	0.05
Fe Iron	[34.0]	[990.]	[1000]	[2.9]
Ga Gallium	220.	210.	440.	1.2
Ge Germanium	220.	210.	440.	1.2
Hg Mercury	1.1	0.71	1.8	0.005
In Indium	110.	71.0	180.	0.51
Li Lithium	5.6	5.0	11.0	0.03
Mn Manganese	5.6	[5.0]	[11.0]	[0.03]
Mo Molybdenum	22.0	21.0	44.0	0.12
Ni Nickel	22.0	21.0	44.0	0.12
Pb Lead	22.0	21.0	44.0	0.12
Sb Antimony	45.0	[420.]	[460.]	[1.3]
Sc Scandium	56.0	50.0	110.	0.29
Se Selenium	1.1	0.71	1.8	0.005
Sn Tin	220.	210.	440.	1.2
Sr Strontium	5.6	5.0	11.0	0.03
Te Tellurium	56.0	50.0	110.	0.29
Ti Titanium	110.	71.0	180.	0.51
Tl Thallium	56.0	50.0	110.	0.29
V Vanadium	5.6	5.0	11.0	0.03
Zn Zinc	[45.0]	[160.]	[160.]	[0.45]

All elements except those in boxes ☐ are below the limit of detection

Table 6.32 Metal Concentrations in Sales Gas Stream at the Shell-Waterton Gas Plant During Test #3

Source: Shell-Waterton Sales Gas | Test No: 3 | Date: April 4, 1983

Sample Analyses	Micrograms		Total Elemental Weight ug	Elemental Concentration ug/rcf
	Probe	Impingers		
Ag Silver	5.4	[6.1]	[11.0]	[0.03]
Al Aluminum	110.	140.	240.	0.62
As Arsenic	0.54	0.54	1.1	0.003
B Boron	1100	1400	2400	6.2
Be Beryllium	2.1	2.0	4.2	0.01
Cd Cadmium	2.1	2.0	4.2	0.01
Co Cobalt	21.0	20.0	42.0	0.11
Cr Chromium	21.0	20.0	42.0	0.11
Cu Copper	11.0	14.0	24.0	0.06
Fe Iron	[43.0]	[120.]	[160.]	[0.42]
Ga Gallium	210.	200.	420.	1.1
Ge Germanium	210.	200.	420.	1.1
Hg Mercury	3.2	3.4	6.6	0.02
In Indium	110.	140.	240.	0.62
Li Lithium	5.4	5.4	11.0	0.03
Mn Manganese	5.4	5.4	11.0	0.03
Mo Molybdenum	21.0	20.0	42.0	0.11
Ni Nickel	21.0	20.0	42.0	0.11
Pb Lead	21.0	20.0	42.0	0.11
Sb Antimony	43.0	41.0	83.0	0.21
Sc Scandium	54.0	54.0	110.	0.28
Se Selenium	1.1	1.4	2.4	0.006
Sn Tin	110.	140.	240.	0.62
Sr Strontium	5.4	5.4	11.0	0.03
Te Tellurium	54.0	54.0	110.	0.28
Ti Titanium	110.	140.	240.	0.62
Tl Thallium	54.0	54.0	110.	0.28
V Vanadium	5.4	5.4	11.0	0.03
Zn Zinc	[41.0]	[95.0]	[140.]	[0.35]

All elements except those in boxes [ ] are below the limit of detection

Table 6.33 Metal Concentrations in Condensate Stabilizer Overhead Stream at the Shell-Waterton Gas Plant During Test #1

Source: Shell-Waterton Condensate Stabilizer Overhead | Test No: 1 | Date: April 4, 1983

Sample Analyses	Micrograms		Total Elemental Weight ug	Elemental Concentration ug/ rcf
	Probe	Impingers		
Ag Silver	5.5	5.1	11.0	0.06
Al Aluminum	110.	100.	210.	1.1
As Arsenic	0.55	0.31	1.4	0.007
B Boron	2200	2000	4200	22.0
Be Beryllium	3.3	3.0	6.3	0.03
Cd Cadmium	5.5	99.0	100.	0.55
Co Cobalt	22.0	20.0	42.0	0.22
Cr Chromium	22.0	71.0	93.0	0.48
Cu Copper	33.0	270.	310.	1.6
Fe Iron	1900	5900	7700	40.0
Ga Gallium	220.	200.	420.	2.2
Ge Germanium	220.	200.	420.	2.2
Hg Mercury	1.1	1.0	2.1	0.01
In Indium	110.	100.	210.	1.1
Li Lithium	5.5	5.1	11.0	0.06
Mn Manganese	30.0	770.	800.	4.2
Mo Molybdenum	55.0	51.0	110.	0.55
Ni Nickel	22.0	20.0	42.0	0.22
Pb Lead	22.0	130.	150.	0.80
Sb Antimony	55.0	51.0	110.	0.55
Sc Scandium	55.0	51.0	110.	0.55
Se Selenium	1.1	1.0	2.1	0.01
Sn Tin	110.	100.	210.	1.1
Sr Strontium	5.5	5.1	11.0	0.06
Te Tellurium	55.0	51.0	110.	0.55
Ti Titanium	110.	100.	210.	1.1
Tl Thallium	55.0	51.0	110.	0.55
V Vanadium	2.2	2.0	4.2	0.02
Zn Zinc	62.0	1300	1400	7.2

All elements except those in boxes ☐ are below the limit of detection

Table 6.34 Metal Concentrations in Condensate Stabilizer Overhead Stream at the Shell-Waterton Gas Plant During Test #2

Source: Shell-Waterton Condensate Stabilizer Overhead | Test No: 2 | Date: April 5, 1983

Sample Analyses	Micrograms		Total Elemental Weight ug	Elemental Concentration ug/rcf
	Probe	Impingers		
Ag Silver	6.0	4.5	11.0	0.05
Al Aluminum	120.	230.	350.	1.7
As Arsenic	0.6	1.0	1.6	0.008
B Boron	2400	2300	4700	23.0
Be Beryllium	2.4	2.3	4.7	0.02
Cd Cadmium	2.4	45.0	48.0	0.24
Co Cobalt	12.0	10.0	22.0	0.11
Cr Chromium	24.0	100.	120.	0.62
Cu Copper	12.0	340.	350.	1.8
Fe Iron	2400	4000	4200	210.
Ga Gallium	240.	230.	470.	2.3
Ge Germanium	240.	230.	470.	2.3
Hg Mercury	1.2	5.7	6.9	0.04
In Indium	120.	100.	220.	1.1
Li Lithium	6.0	4.5	11.0	0.05
Mn Manganese	59.0	890.	940.	4.7
Mo Molybdenum	24.0	23.0	47.0	0.23
Ni Nickel	24.0	23.0	47.0	0.23
Pb Lead	24.0	45.0	69.0	0.35
Sb Antimony	48.0	45.0	93.0	0.47
Sc Scandium	60.0	45.0	110.	0.53
Se Selenium	1.2	1.0	2.2	0.01
Sn Tin	240.	230.	470.	2.4
Sr Strontium	6.0	4.5	11.0	0.05
Te Tellurium	60.0	45.0	110.	0.53
Ti Titanium	120.	100.	220.	1.1
Tl Thallium	60.0	45.0	110.	0.53
V Vanadium	6.0	4.5	11.0	0.05
Zn Zinc	24.0	1700	1700	8.7

All elements except those in boxes ☐ are below the limit of detection

Table 6.35 Metal Concentrations in Condensate Stabilizer Overhead Stream at the Shell-Waterton Gas Plant During Test #3

Source: Shell-Waterton Condensate Stabilizer Overhead | Test No: 3 | Date: April 5, 1983

Sample Analyses	Micrograms		Total Elemental Weight ug	Elemental Concentration ug/rcf
	Probe	Impingers		
Ag Silver	8.0	5.4	13.0	0.05
Al Aluminum	130.	4700	4900	18.0
As Arsenic	0.67	3.2	3.9	0.01
B Boron	1300	1300	2700	10.0
Be Beryllium	2.7	1.3	4.0	0.02
Cd Cadmium	2.7	1.3	4.0	0.02
Co Cobalt	27.0	13.0	40.0	0.15
Cr Chromium	27.0	54.0	81.0	0.31
Cu Copper	13.0	9.4	23.0	0.09
Fe Iron	93.0	2600	2700	10.0
Ga Gallium	270.	270.	540.	2.0
Ge Germanium	270.	270.	540.	2.0
Hg Mercury	0.27	40.0	41.0	0.15
In Indium	130.	94.0	230.	0.86
Li Lithium	6.7	5.4	12.0	0.05
Mn Manganese	6.7	53.0	59.0	0.23
Mo Molybdenum	27.0	13.0	40.0	0.15
Ni Nickel	27.0	13.0	40.0	0.15
Pb Lead	27.0	13.0	40.0	0.15
Sb Antimony	53.0	40.0	94.0	0.36
Sc Scandium	67.0	54.0	120.	0.46
Se Selenium	1.3	1.3	2.7	0.01
Sn Tin	130.	94.0	230.	0.86
Sr Strontium	6.7	5.4	12.0	0.05
Te Tellurium	67.0	54.0	120.	0.46
Ti Titanium	130.	94.0	230.	0.86
Tl Thallium	67.0	54.0	120.	0.46
V Vanadium	6.7	5.4	12.0	0.05
Zn Zinc	130	320	450	1.7

All elements except those in boxes ☐ are below the limit of detection

Table 6.36 Metal Concentrations in SCOT Plant Inlet Stream at the Shell-Waterton Gas Plant During Test #1

Source: Shell-Waterton Inlet to SCOT Plant | Test No: 1 | Date: April 6, 1983

Sample Analyses	Micrograms Probe	Micrograms Impingers	Total Elemental Weight ug	Elemental Concentration ug/rcf
Ag Silver	4.3	5.6	9.9	0.13
Al Aluminum	86.0	220.	310.	3.9
As Arsenic	0.43	0.56	0.99	0.01
B Boron	1700	2200	3900	50.0
Be Beryllium	2.6	3.3	5.9	0.08
Cd Cadmium	1.7	2.2	3.9	0.05
Co Cobalt	17.0	22.0	39.0	0.50
Cr Chromium	17.0	110.	130.	1.6
Cu Copper	8.6	22.0	31.0	0.39
Fe Iron	950.	87000	88000	1100
Ga Gallium	170.	220.	390.	5.0
Ge Germanium	170.	220.	390.	5.0
Hg Mercury	0.86	1.1	2.0	0.03
In Indium	86.0	110.	200.	2.5
Li Lithium	4.3	5.6	9.9	0.13
Mn Manganese	12.0	2200	2200	28.0
Mo Molybdenum	43.0	56.0	99.0	1.3
Ni Nickel	17.0	22.0	39.0	0.50
Pb Lead	17.0	22.0	39.0	0.50
Sb Antimony	43.0	56.0	99.0	1.3
Sc Scandium	43.0	56.0	99.0	1.3
Se Selenium	0.86	1.1	2.0	0.03
Sn Tin	86.0	110.	200.	2.5
Sr Strontium	4.3	5.6	9.9	0.13
Te Tellurium	43.0	56.0	99.0	1.3
Ti Titanium	86.0	110.	200.	2.5
Tl Thallium	43.0	56.0	99.0	1.3
V Vanadium	1.7	22.0	24.0	0.30
Zn Zinc	130.	670.	800.	10.0

All elements except those in boxes ☐ are below the limit of detection

Table 6.37 Metal Concentrations in SCOT Plant Inlet Stream at the Shell-Waterton Gas Plant During Test #2

Source: Shell-Waterton Inlet to SCOT Plant | Test No: 2 | Date: April 6, 1983

Sample Analyses	Micrograms Probe	Micrograms Impingers	Total Elemental Weight ug	Elemental Concentration ug/rcf
Ag Silver	6.1	5.4	12.0	0.19
Al Aluminum	120.	90.0	210.	3.6
As Arsenic	0.61	0.54	1.2	0.02
B Boron	2400	1800	4200	71.0
Be Beryllium	2.4	1.8	4.2	0.07
Cd Cadmium	3.7	16.0	20.0	0.33
Co Cobalt	12.0	9.0	21.0	0.36
Cr Chromium	24.0	32.0	56.0	0.94
Cu Copper	12.0	9.0	21.0	0.36
Fe Iron	2700	340000	340000	5800.
Ga Gallium	240.	180.	420.	7.1
Ge Germanium	240.	180.	420.	7.1
Hg Mercury	1.2	0.9	2.1	0.04
In Indium	120.	90.0	210.	3.6
Li Lithium	6.1	5.4	12.0	0.19
Mn Manganese	31.0	3200	3300	55.0
Mo Molybdenum	24.0	18.0	42.0	0.71
Ni Nickel	24.0	18.0	42.0	0.71
Pb Lead	24.0	18.0	42.0	0.71
Sb Antimony	49.0	45.0	94.0	1.6
Sc Scandium	6.1	54.0	60.0	1.0
Se Selenium	1.2	0.90	2.1	0.04
Sn Tin	240.	180.	420.	0.71
Sr Strontium	6.1	5.4	12.0	0.19
Te Tellurium	61.0	54.0	120.	1.9
Ti Titanium	122.	90.0	210.	3.6
Tl Thallium	61.0	54.0	120.	1.9
V Vanadium	6.1	5.4	12.0	0.19
Zn Zinc	27.0	360.	390.	6.5

All elements except those in boxes ☐ are below the limit of detection

Table 6.38 Metal Concentrations in SCOT Plant Inlet Stream at the Shell-Waterton Gas Plant During Test #3

Source: Shell-Waterton Inlet to SCOT Plant Test No: 3 Date: April 7, 1983

Sample Analyses	Micrograms Probe	Micrograms Impingers	Total Elemental Weight ug	Elemental Concentration ug/rcf
Ag Silver	9.0	7.9	17.0	0.23
Al Aluminum	130.	110.	230.	3.2
As Arsenic	0.65	0.53	1.2	0.02
B Boron	1300	1300	2600	35.0
Be Beryllium	2.6	2.6	5.2	0.07
Cd Cadmium	2.6	2.6	5.2	0.07
Co Cobalt	26.0	26.0	52.0	0.71
Cr Chromium	26.0	26.0	52.0	0.71
Cu Copper	13.0	11.0	23.0	0.32
Fe Iron	6500	29000	35000	480.
Ga Gallium	260.	260.	520.	7.1
Ge Germanium	260.	260.	520.	7.1
Hg Mercury	3.9	2.6	6.5	0.09
In Indium	130.	110.	230.	3.2
Li Lithium	6.5	5.3	1.2	0.16
Mn Manganese	25.0	400.	420.	5.7
Mo Molybdenum	26.0	26.0	52.0	0.71
Ni Nickel	26.0	26.0	52.3	0.71
Pb Lead	26.0	26.0	52.0	0.71
Sb Antimony	52.0	40.0	91.0	1.2
Sc Scandium	65.0	53.0	120.	1.6
Se Selenium	1.3	1.3	2.6	0.04
Sn Tin	130.	110.	230.	3.2
Sr Strontium	6.5	5.3	12.0	0.16
Te Tellurium	65.0	53.0	120.	1.6
Ti Titanium	130.	110.	230.	3.2
Tl Thallium	65.0	53.0	120.	1.6
V Vanadium	6.5	5.3	12.0	0.16
Zn Zinc	62.0	710.	770.	10.0

All elements except those in boxes ☐ are below the limit of detection

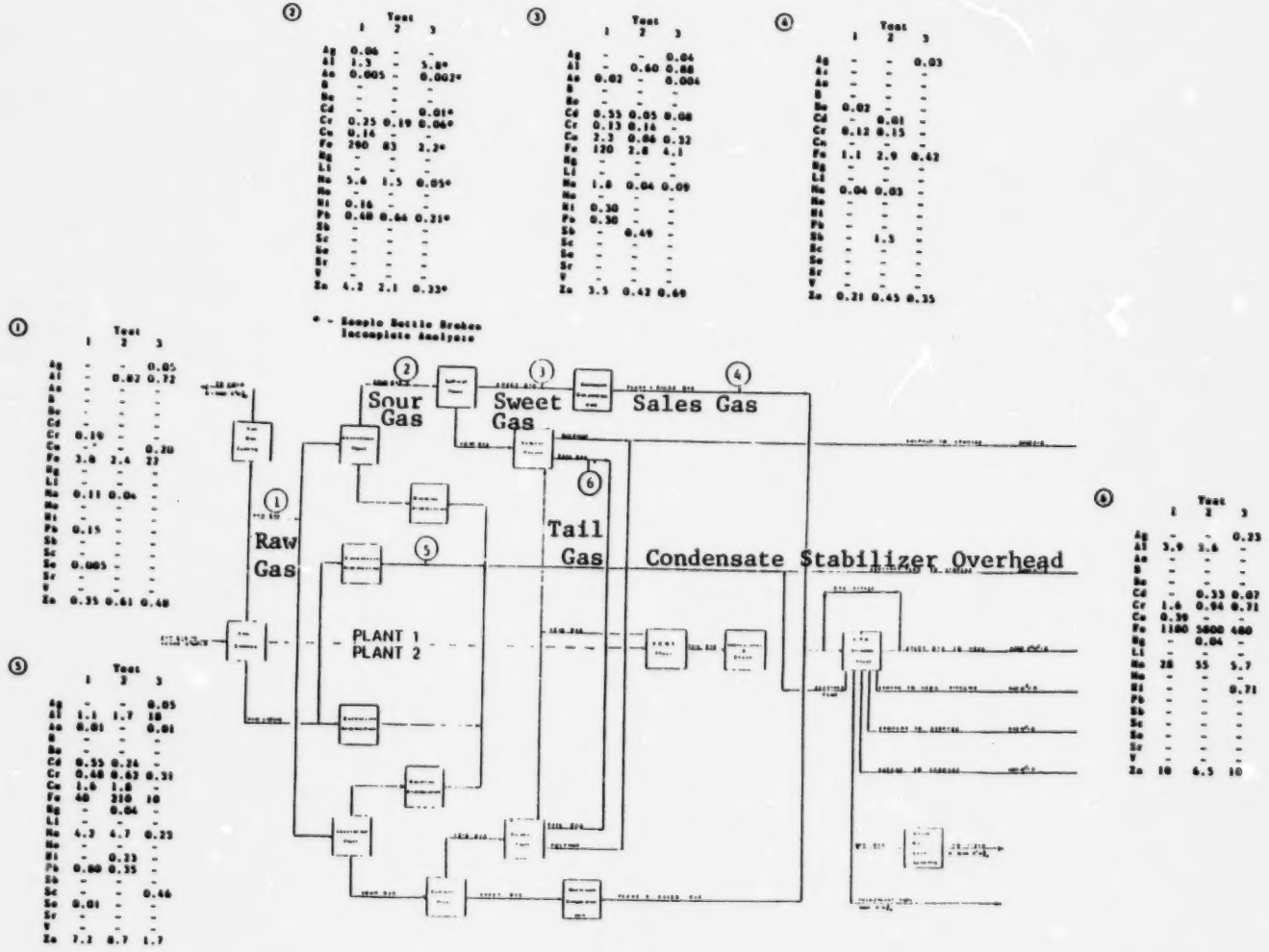

Figure 6.2 Summary of Metal Concentrations in Various Process Streams at the Shell Canada Resources Limited Waterton Gas Plant (µg/rcf)

VII DISCUSSION OF RESULTS

This investigation was designed to complement an earlier study (2) of trace metal emission rates from the incinerator stacks at the Gulf-Pincher Creek and Shell-Waterton Sour Gas Plants. The objective was to establish the concentrations of the 29 metals of interest in the process streams that could be diverted to flare stacks in the event of plant upsets.

A. PINCHER CREEK GAS PLANT (GULF)

It was shown by a previous incinerator stack sampling program (2) that

- aluminum
- copper
- iron
- titanium
- zinc

were consistently present, in the gases exhausted from the incinerator stack, at concentrations significantly above the detection limits. The identification of

- cadmium (1 out of 3 tests)
- lithium (1 out of 3 tests)
- antimony (1 out of 3 tests)

at levels just above detection limits suggested that these metals could be released into the atmosphere intermittently at trace concentration levels (2).

An examination of Figure 6.1 shows that

- aluminum
- arsenic
- cadmium
- chromium
- copper
- iron
- lead
- manganese
- nickel
- zinc

were found consistently in the various process streams. In addition the presence of

- antimony
- beryllium
- boron
- lithium
- mercury
- molybdenum
- silver
- vanadium

was detected at least once during the sampling program.

With the exception of

- antimony
- beryllium
- lithium

- molybdenum

all the other metals were identified at least once in the raw sour gas stream leaving the Inlet Separators (at the Amine Contactor Inlet).

Without additional comprehensive analyses of the operations of typica' sour gas plants it is not possible to establish conclusively that all of the metals detected in the raw sour gas stream originated in the formations of the Lookout Butte and Pincher Creek gas fields. It is difficult to assess the contributions of metallic species from additions of

- bactericides
- corrosion inhibitors
- scale inhibitors

that are made at the well heads. Discussions with a supplier of chemicals to the Gulf-Pincher Creek Sour Gas Plant (9) indicated that the commercial products

- K-142 (corrosion inhibitor - hydrocarbons)
- K-147 (corrosion inhibitor - water phase)
- WF-95 (combination corrosion and scale inhibitor)
- WF-1640 (bactericide)

were routinely used for control purposes. Because of proprietory restrictions it was not possible to get any estimates of metal contents of these additives.

The decommissioning of the Gulf-Pincher Creek Sour Gas Plant following the transfer of ownership to Palmer Ranch Ltd. provided a basis for confirming the presence of the metallic

species at the different sampling locations illustrated in Figure 6.1. The results of metal analyses of

- amine treatment chemicals
- amine contactor components
- cooling water treatment chemicals
- fresh and used silica gels
- used bauxite catalysts

are summarized in Tables 7.1, 7.2, 7.3, 7.4 and 7.5 respectively.

Although it is not possible to make a quantitative assessment of the contributions of different chemical additives to the metal burdens of the various process streams, it is, nevertheless, reasonable to argue that as a result of routine plant operations metals can accumulate and/or circulate according to the patterns illustrated in Figure 6.1. Cross-circuiting of cooling water as a result of leaks in the system must be considered as a potential source of, at least, some of the metals identified in Figure 6.1.

B. WATERTON GAS PLANT (SHELL)

An earlier stack sampling program (2) established the presence of

- aluminum
- copper
- iron
- tin
- titanium
- zinc

Table 7.1 Heavy Metal Analyses of Amine Treatment Chemicals (10)

Metal	Chemical			
	Antifoam B	Soda Ash	WS-58 (Corrosion Inhibitor)	Sulfamic Acid
	µg/Imp Gal	µg/kg	µg/Imp Gal	µg/kg
Ag	<90	<10	<90	<4
Al	<300	2900	14000	<15
As	<600	<60	<600	<25
B	<100	1500	7000	<5
Be	n/a	n/a	n/a	n/a
Cd	<20	60	900	10
Cr	270	130	23000	130
Cu	<50	80	18000	<2
Fe	<50	2900	1,690,000	1400
Hg	<10	50	440	130
Li	n/a	n/a	n/a	n/a
Mn	<200	5	8000	20
Mo	<100	300	12000	40
Ni	270	100	63000	63
Pb	<500	400	7000	340
Sb	n/a	n/a	n/a	n/a
Se	<500	<50	<500	<20
Sn	n/a	n/a	n/a	n/a
Sr	n/a	n/a	n/a	n/a
V	<50	100	700	<2
Zn	500	200	24000	42

n/a = not analyzed

Laboratory and QA/QC program not described

Table 7.2 Heavy Metal Analyses of Amine Contactor Components (10)

Metal	Component	
	Diethanolamine	Diatomaceous Earth Cellulose Product (Unused Amine Filter)
	µg/Imp Gal	µg/kg
Ag	<90	<10
Al	<300	160000
As	<600	<80
B	16000	1300
Be	n/a	n/a
Cd	<20	70
Cr	2700	5400
Cu	<50	370
Fe	<50	59000
Hg	420	20
Li	n/a	n/a
Mn	470	600
Mo	1500	1300
Ni	<100	700
Pb	3200	800
Sb	n/a	n/a
Se	<500	<70
Sn	n/a	n/a
Sr	n/a	n/a
V	<50	6800
Z	1600	700

n/a = not analyzed

Laboratory and QA/QC program not described

Table 7.3 Heavy Metal Analyses of Cooling Water Treatment Chemicals (10)

Metal	Chemical				
	Alchem 345	Alchem 375	Alchem 7319	Alchem 321	Ferrous Sulfate
	µg/Imp Gal	µg/Imp Gal	µg/Imp Gal	µg/Imp Gal	µg/kg
Ag	1000	21000	500	2000	100
Al	44000	51000	6000	14300	<40
As	2000	453000	n/a	3000	<60
B	25000	15000	17800	14000	<10
Be	n/a	n/a	n/a	n/a	n/a
Cd	11000	12000	3500	13000	<20
Cr	18000	6.1×10^8	8000	518000	<10
Cu	11000	36000	21000	147000	820
Fe	43000	89000	39400	50000	2×10^8
Hg	<100	100	<100	<1000	7100
Li	n/a	n/a	n/a	n/a	n/a
Mn	100	11000	500	2000	1×10^6
Mo	43000	39000	200	<1000	10
Ni	4000	35000	2800	16000	8800
Pb	94000	142000	39300	107000	7300
Sb	n/a	n/a	n/a	n/a	n/a
Se	504000	95000	n/a	<1000	97000
Sn	n/a	n/a	n/a	n/a	n/a
Sr	n/a	n/a	n/a	n/a	n/a
V	300	125000	300	<1000	5
Zn	38000	618000	3800	112000	75000

n/a = not analyzed

Laboratory and QA/QC program not described

Table 7.4 Heavy Metal Analyses of Silica Gel (10)

Metal	State of Silica Gel			
	Fresh	Used (Leachable Metal Test)		
		pH=3.5	pH=1.4	not indicated
	ppm	ppm	ppm	ppm
Ag	<0.005	n/a	n/a	n/a
Al	52	n/a	n/a	n/a
As	<0.035	n/a	n/a	n/a
B	0.080	n/a	n/a	n/a
Be	n/a	n/a	n/a	n/a
Cd	0.041	<0.06	<0.06	<0.1
Cr	0.40	<1.5	<1.5	45
Cu	0.11	3.5	4.1	16
Fe	26	942	1370	35800
Hg	0.090	n/a	n/a	n/a
Li	n/a	n/a	n/a	n/a
Mn	0.053	21.3	21.4	60
Mo	0.12	n/a	n/a	n/a
Ni	0.12	2.6	2.8	12
Pb	0.49	<0.3	<0.3	n.d.
Sb	n/a	n/a	n/a	n/a
Se	<0.027	n/a	n/a	n/a
Sn	n/a	n/a	n/a	n/a
Sr	n/a	n/a	n/a	n/a
V	0.19	<3	<.1	n.d.
Zn	0.46	0.3	0.01	0.9

n/a = not analyzed

n.d. = not detected

Laboratory and QA/QC program not described

Table 7.5 Summary of Heavy Metal Analyses of Twelve Used Bauxite Catalyst Samples Subjected to Total Acid Digestion (10)

Metal	Lowest Level ppm	Highest Level ppm
Ag	0.3	8
Al	1.1×10^5	8.8×10^5
As	<25 ppb	<1
B	2	65
Be	n/a	n/a
Cd	7	51
Cr	8	113
Cu	0.4	93
Fe	$.12 \times 10^4$	4.6×10^4
Hg	0.6	2.9
Li	n/a	n/a
Mn	6	506
Mo	17	82
Ni	2	154
Pb	33	168
Sb	n/a	n/a
Se	<20 ppb	8
Sn	16	283
Sr	n/a	n/a
V	2	890
Zn	3	198

n/a = not analyzed

Laboratory and QA/QC program not described

in the incinerator stack gases at the Waterton plant. Sporadic detection of

- antimony (2 out of 5 tests)
- arsenic (1 out of 5 tests)
- chromium (2 out of 5 tests)
- germanium (1 out of 5 tests)
- manganese (1 out of 5 tests)
- scandium (1 out of 5 tests)
- selenium (1 out of 5 tests)

occurred at levels just above the limits of detection (2).

According to Figure 6.2, the raw sour gases leaving the Slug Catchers (sample site #1 at the inlet to the Lean Oil Absorption Units) were relatively free of metals. Only iron and zinc were determined consistently at sampling location #1. Consequently the presence of any metal in a process stream may be the result of additions of

- processing chemicals
- bactericides
- corrosion inhibitors
- scale inhibitors

during routine operation of the plant.

Since the presence of

- tin
- titanium
- germanium

was never detected in any process stream in the Waterton Gas Plant it is difficult to explain their identification in the gases exhausted from the incinerator stack during an earlier study (2).

Titanium emissions can be rationalized in terms of erosion of refractory materials used to line different high temperature processing units and stacks. Data supplied by Shell Canada Resources Limited (11) indicate that some refractories can contain up to 3.5% by weight of titania (T_1O_2).

An independent trace element investigation (12) of the ambient air entering the incinerator stack burner at the Shell-Waterton Gas Plant identified the presence of

- aluminum (7 out of 7 tests)
- arsenic (5 out of 7 tests)
- copper (7 out of 7 tests)
- gallium (3 out of 7 tests)
- germanium (1 out of 7 tests)
- iron (7 out of 7 tests)
- manganese (7 out of 7 tests)
- selenium (5 out of 7 tests)
- strontium (3 out of 7 tests)
- vanadium (1 out of 7 tests)
- zinc (7 out of 7 tests).

VIII CONCLUSIONS AND RECOMMENDATIONS

The presence of aluminum, arsenic, cadmium, chromium, copper, iron, lead, manganese, nickel and zinc was established consistently in the various process streams of the Gulf-Pincher Creek Sour Gas Plant. Antimony, beryllium, boron, lithium, mercury, molybdenum, silver and vanadium were identified at least once during the three-test sampling program.

At the Shell-Waterton Sour Gas Plant only cadmium, chromium, iron, manganese and zinc appeared regularly in each of the process streams sampled. Aluminum, antimony, arsenic, beryllium, copper, lead, mercury, nickel, scandium, selenium and silver were detected at least once at one or more of the sampling locations.

The results of this sampling program suggest that flaring operations resulting from plant upsets can be responsible for the emission of broader spectra of metallic species than those associated with corresponding incinerator stack exhaust gases. At the present time it is not possible to assess the impacts of flare stack emissions on downwind receptors because pertinent data are not readily available for atmospheric dispersion calculations.

If atmospheric dispersion modelling of the emissions from flare stacks is to be carried out in the future it is recommended that serious efforts be made to

- determine the volumetric flow rates of each of the process streams that can be flared in the event of a plant upset condition
- establish the historical frequencies with which the individual process streams have been directed to flare stacks
- evaluate the average time intervals over which the individual process streams have been diverted to flare stacks.

It is also recommended that a comprehensive survey be carried out at the Shell-Waterton Sour Gas Plant to establish the extent of metal inputs into the process streams as a result of additions of

- processing components
- bactericides
- corrosion inhibitors
- scale inhibitors
- antifoam agents.

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APPENDIX I

TECHNICAL DATA ON ULTRA-PURE QM-A QUARTZ MICROFIBRE FILTERS

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TECHNICAL DATA ON

ULTRA-PURE QM-A QUARTZ FILTERS

QM-A QUARTZ TECHNICAL DATA

Basis Weight ..... 85 gm/m²
Thickness ..... 0.45 mm
Particle retention efficiency ..... 99.999% retention
(0.6 μm particles at 5cm/sec F.V.) or 0.001% penetration
Dry Tensile (1.5 cm wide strip) ..... 250 – 300 g
Maximum Temperature ..... 500° C
Air flow rate ..... 800 litres/min
(for 400 cm² filter area at Δ p = 20 mm Hg)

N.B. 400 cm² is effective filtration area of 8" x 10" sheet

CHEMICAL PURITY

Element	p.p.m.	Micrograms per sheet (8 x 10 in)
Cd	0.23	1
Co	1.1	5
Cr	1.6	7
Cu	3.4	15
Fe	23.0	100
Mn	0.46	2
Ni	3.4	15
Pb	2.3	10
Zn	18.2	80

All values typical subject to normal manufacturing tolerances.

QM-A. THE NEW ULTRA-PURE QUARTZ FILTER FROM WHATMAN FOR AIR SAMPLING.

Whatman now introduce QM-A, an ultra-pure quartz (SiO_2) microfibre filter for the most exacting work in air pollution monitoring. QM-A is heat-treated and entirely binder free and only a small amount (5%) of conventional borosilicate glass microfibres are added for papermaking purposes.

ULTRA-PURE – HIGH FLOW RATES

Ultra-pure QM-A is extremely low in heavy metal content, whilst offering the high flow rates and filtration efficiencies of conventional borosilicate glass microfibre filters. Trace level determinations in particulates can now be carried out with the utmost accuracy.

LOW IN ALKALINE EARTH METALS

Whatman QM-A contains virtually no alkaline earth metals and is therefore recommended for sampling and subsequent analysis of environments where acidic gases such as SO_2 and NO_2 are encountered. 'Artifact' production of sulphates and nitrates on the filter, is, thus, virtually eliminated with QM-A and critical analyses can now be conducted free from inaccuracies caused by artifact production with glass microfibre filters.

APPLICATIONS

Whatman QM-A is suitable for ambient and high temperature (max 500° C) air sampling of environments such as stacks, flue outlets and aerosols. Being ultrapure and containing low levels of elements important in pollution studies, Whatman QM-A is the filter of choice for critical analyses and trace level determinations, and it is especially suitable for analytical techniques such as atomic absorption spectroscopy and flame emission spectrophotometry.
The low background levels of heavy metals in QM-A also make it suitable for X-ray fluorescence techniques and neutron activation analyses

MINIMAL WEIGHT LOSS

QM-A is heat treated after manufacture to remove bound moisture and trace organic impurities and to ensure minimal weight loss on further heating. For accurate gravimetric results, as with any medium, it is essential, both before and after sampling, to condition the filter carefully before weighing.

AVAILABILITY

Standard Sizes		Cat. No.
Circles:	3.2 cm dia	1851 032
	3.7	1851 037
	4.7	1851 047
	5.5	1851 055
Sheets:	20.4 x 25.4 cm (8 x 10 in)	1851 865

PUBLICATION NO 860 QM-A A

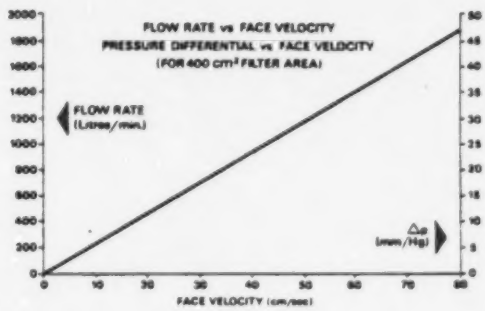
COMPARISON OF PHYSICAL CHARACTERISTICS AND CHEMICAL PURITY OF WHATMAN QM-A QUARTZ MICROFIBRE FILTERS, EPM1000, GF/A AND GRADE 41

(1) PHYSICAL CHARACTERISTICS:

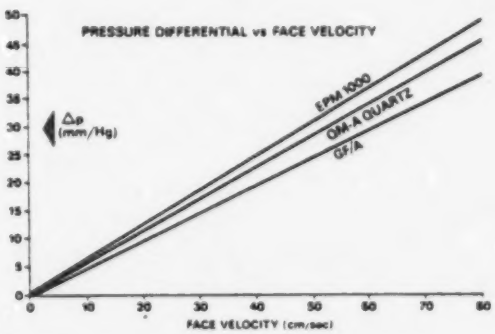
	QM-A	EPM1000	GF/A	No. 41
Composition	**Quartz Microfibre**	**Glass Microfibre**	**Glass Microfibre**	**Cellulose (Cotton Linters)**
Basis weight	85	80	53	85
Thickness (mm)	0.45	0.43	0.26	0.21
Dry Tensile[2] (g)	250-300	742	430	2400
Sodium Flame Retention[3] (NaFla) (%)	99.999	99.999	99.995	74
ΔP[4] (mm Hg)	3	3	3	3
Temperature Resistance (Max. °C)	500	500	500	200
Air[5] Flow Rate at $\Delta P = 3$	120	120	120	120
Air[5] Flow Rate at $\Delta P = 20$	800	750	950	1150

NOTES
[1] All values are 'typical' and subject to normal manufacturing tolerances
[2] Tensile 1.5 cm wide strip
[3] Sodium flame penetrometer to BS 4400 all values at 5cms/Sec F.V
[4] Pressure differential across filter at 5cms/Sec F.V
[5] Measured in litre/minute for air (values for 400 cm^2 area assuming no flow restriction imposed by holder)
Key F.V. = Face Velocity
NB ΔP figures at higher FV's than 5 cms/sec vary considerably with grade of filter – see Air Pollution Monitoring brochure for graphs of ΔP vs F.V

QM-A QUARTZ FILTER FLOW RATE



COMPARISON OF QM-A QUARTZ, EPM1000 AND GF/A



(2) CHEMICAL PURITY Concentrations given in µg/sheet (8" x 10") and in p.p.m.

	QM-A		EPM1000		GF/A		GRADE 41	
Element	**µg/sheet**	**p.p.m.**	**µg/sheet**	**p.p.m.**	**µg/sheet**	**p.p.m.**	**µg/sheet**	**p.p.m.**
Cd	1.0	0.23	2.1	0.5	2.7	1.0	ND	ND
Co	4.8	1.1	1.24	0.3	2.7	1.0	ND	ND
Cr	7.0	1.6	4.95	1.2	0.55	0.2	1.3	0.3
Cu	14.9	3.4	2.9	0.7	16.4	6.0	1.75	0.4
Fe	100	23	103	25	275	100	28.3	6.0
Mn	2.0	0.46	4.95	1.2	21.9	8.0	<0.22	<.05
Ni	14.9	3.4	14.4	3.5	16.4	6.0	ND	ND
Pb	10.0	2.3	10.3	2.5	27	10	0.9	0.2
Zn	80	18.2	103	25	ND	ND	2.6	0.6

KEY ND = NOT DETERMINED

NOTES Cellulose Data obtained from analysis of ash. Glass Data obtained from extraction under acid conditions.

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APPENDIX II

PREPARATION OF DIMINERALIZED WATER

AND

ACTUAL LOT ANALYSIS (218042) FOR

BAKER INSTRA-ANALYZED NITRIC ACID

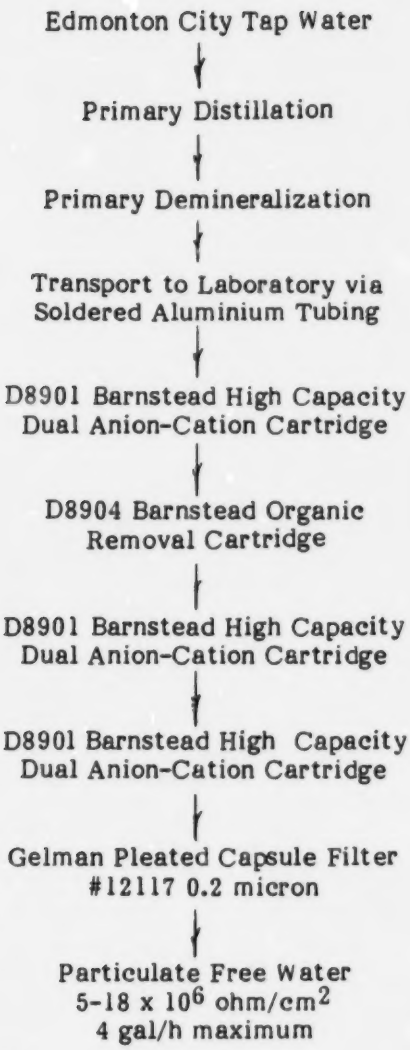
Edmonton City Tap Water
Primary Distillation
Primary Demineralization
Transport to Laboratory via Soldered Aluminium Tubing
D8901 Barnstead High Capacity Dual Anion-Cation Cartridge
D8904 Barnstead Organic Removal Cartridge
D8901 Barnstead High Capacity Dual Anion-Cation Cartridge
D8901 Barnstead High Capacity Dual Anion-Cation Cartridge
Gelman Pleated Capsule Filter #12117 0.2 micron
Particulate Free Water
5-18 x 10^6 ohm/cm^2
4 gal/h maximum

Figure II.1 Preparation of Demineralized Water by Energy Resources Conservation Board Laboratory, Edmonton, Alberta

APPENDIX II

Assay (HNO_3) (by acid base titration)	70.3%
Appearance	Passes test
Color (APHA)	< 5
Density at 20°C	1.426 gm/ml
Residue after ignition	2 ppm

Trace Impurities (ppm) (µg/g)

Chloride (Cl)	< 0.08	Lead (Pb)	0.0002
Phosphate (PO_4)	< 0.1	Lithium (li)	< 0.02
Sulphate (SO_4)	< 0.5	Magnesium (Mg)	0.02
Aluminum (Al)	0.05	Manganese (Mn)	0.0004
Arsenic and Antimony (as As)	< 0.005	Mercury (Hg)	< 0.0001
Barium (Ba)	< 0.02	Nickel (Ni)	0.003
Boron (B)	0.001	Potassium (K)	< 0.1
Cadmium (Cd)	< 0.002	Silicon (Si)	0.01
Calcium (Ca)	0.02	Silver (Ag)	< 0.0001
Chromium (Cr)	0.02	Sodium (Na)	0.2
Cobalt (Co)	0.0002	Strontium (Sr)	< 0.002
Copper (Cu)	0.0003	Tin (Sn)	0.001
Heavy Metals (as Pb)	0.05	Zinc (Zn)	< 0.002
Iron (Fe)	0.02		

Table II.1 Actual Lot Analysis (218042) for Baker Instra-Analyzed Nitric Acid